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Behavioral and Neural Correlates of Misses During Cued Recall

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BEHAVIORAL AND NEURAL CORRELATES OF MISSES DURING CUED RECALL

A Thesis

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in

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by

Lindsey Ann Sirianni

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ABSTRACT

Recognition memory is thought to rely upon both recollection and familiarity. When people recall an episode from the past it is generally considered to reflect the memory process of recollection. Therefore, if people can successfully recall an item, they should be able to recognize it. However, in cued recall paradigms of memory research, participants sometimes correctly recall a studied target word in the presence of a strong semantic cue but then fail to recognize that word as actually having been studied. This paradox and underlying cognitive processes have been minimally studied by scientists, leaving this phenomenon poorly understood. Extant research has investigated some of the conditions necessary to produce these conditions but not the underlying neural correlates that drive them. The present study builds upon earlier studies using Electroencephalogram (EEG) to investigate the neural processes that underlie recognition failures of successfully recalled words. In the present experiment, participants studied words one at a time, and then later were asked to verbally recall these previously studied words as cued by their semantic associates. Following the participant’s verbal response, their recognition memory was tested for the recalled word. The current study aimed to use physiological measures (EEG) to investigate the explicit and implicit cognitive processes that may be involved in the recognition failure of recalled words. The data indicate that successfully recalled words that are recognized are driven by recollection at recall and a combination of recollection and familiarity at recognition, whereas

successfully recalled words that are not recognized are instead driven by semantic priming at recall and at recognition, are driven by negative-going ERP effects reflecting implicit processes such as repetition fluency.

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CHAPTER ONE

INTRODUCTION

Explicit Memory

One of the fundamental distinctions between memory systems depends on whether or not they support conscious access to memories (Cohen & Eichenbaum, 1993; Corkin, 2002; Hannula & Greene, 2012; Reagh & Ranganath, 2018; Reber, 2013; Schacter, Chui, & Ochsner, 1993; Squire, 2004; Suthana & Fried, 2012; Tulving & Markowitsch, 1998). The predominant delineation of long-term memory suggests a two-part system consisting of explicit and implicit memory, also referred to as declarative and non-declarative memory respectively (Cohen & Squire, 1980; Gabrieli, 1998; Squire, 2004; Squire & Dede, 2015; Squire & Zola-Morgan, 1991). Explicit memory involves the conscious recall of people, places and events (Polster, Nadel, & Schacter, 1991; Squire & Dede, 2015; Tulving, 1993; Yonelinas, 2001), whereas non-conscious or implicit memory involves motor skills, priming, sensitization, habituation, and associative forms such as classical conditioning (Bailey, Bartsch, & Kandel, 1996; Barco, Bailey, & Kandel, 2006; Reber, 2013; Rosenthal & Soto, 2016; Schacter et al., 1993; Tulving & Schacter, 1990).

A subset of explicit memory is episodic memory, which involves the conscious remembering of specific events and episodes. Episodic memory can be attained via recognition. Recognition is thought to rely on two distinct processes: recollection and familiarity (Woodruff, Hayama, & Rugg, 2006; Gardiner, 1988; Jacoby, 1991; Mandler, 1980; Tulving, 1985), as described by the dual process model of recognition memory (Yonelinas, 1994). According to Diana, Yonelinas, and Ranganath (2007), familiarity is the “process of recognizing an item on the basis of its perceived memory strength but without retrieval of any specific details about the study episode” (Yonelinas, 2002; Yonelinas, Aly, Wang, & Koen, 2010). In other words, familiarity reflects an intuitive feeling that a stimulus was recently experienced and can be described as a vague sense of remembering without contextual information. For example, seeing a remembered face but not being able to identify the individual or the context in which they were encountered might elicit a sense of familiarity. By contrast, recollection is considered to be a reconstructive process in which the details and contextual information about an item’s prior occurrence are retrieved. For example, recollection can be described with contextual information, such as seeing a face and knowing that person’s name as well as the when and where they were met.

Different tasks have been successful in tapping into the processes of recollection and familiarity to reveal their respective characteristics. The two most ubiquitous tests of episodic memory retrieval are recognition and recall (Yonelinas, 2002). In old/new recognition paradigms, participants begin by studying a series of stimuli (often words). At test, studied (old) stimuli are mixed with new stimuli and participants must identify each item as either “old” or “new.”

Identifying a studied word as "old" is considered a *hit* (deriving from signal detection nomenclature), whereas identifying a studied word as "new" is a *miss.* Additionally, identifying a new word as "new" is a *correct rejection* and incorrectly identifying a new word as "old" is a *false alarm*. In recall paradigms, participants also begin by studying a series of words, but at test they must verbally generate as many studied words as possible, sometimes with the assistance of semantic associate cues[1]. In typical recall paradigms, since participants are simply asked to produce as many studied words as possible, there are no equivalents to hits and misses. However, when participants are asked during recall not only to generate studied items but also to identify each produced item as either "old" or "new"—referred to henceforth as forced-recall-recognition paradigms—hits and misses can be calculated and are analogous to hits and misses in standard recognition. Thus, producing a studied word and identifying it as "old" is a hit, whereas producing a studied word and identifying it as "new" is a miss and producing a new word and identifying it as "new" is a correct rejection.

Although both recognition and recall are each considered explicit retrieval tasks, recall is widely viewed as the more demanding form of retrieval (Kintsch, 1968; Yonelinas et al., 2002). Since test probes are provided to participants in recognition paradigms, either an intuitive sense of familiarity or an explicit conscious recollection can be used to judge whether the probe was recently experienced. However, for recall paradigms a participant must actively retrieve

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[1] Unless otherwise noted, this paper primarily examines cued recall using semantic associates as cues. In this paradigm, participants typically study a list of individual words, and then at test

an item from memory. Therefore conscious recollective processes are often deemed necessary, as feelings of familiarity are insufficient to retrieve and produce items. This can be thought of in computational terms, such that familiarity can be retrieved by virtue of a generic, cue-responding pattern separation process, but recollection can be alternatively modeled as a pattern completion process that can autocomplete the retrieval of an episode in the absence of a given cue (Yassa & Stark, 2011). In terms of memory paradigms, few tasks or behaviors are thought to be more explicit or demanding of recollection than recall, which on this basis has been used to dissociate retrieval processes in clinical cases of amnesia and medial temporal lobe pathologies (Yonelinas et al., 2004).

As a corollary of this standard account of recall, which suggests that recall is more demanding than recognition, it is assumed that items that are recalled should also be recognized. Researchers have traditionally used forced-recall-recognition procedures to investigate this issue, requiring participants not only to recall studied words but also to identify each word that they produce as either “old” (studied) or “new” (i.e., a guess). In most cases, when participants are able to recall a studied word, they are also able to recognize it as “old” (i.e. a recall hit followed by a recognition hit). This makes intuitive and logical sense, as people should inherently recognize information that has just been recalled through processes assumed to reflect recollection. However, a paradoxical effect arises on some trials: Participants reliably recall studied words which they then cannot recognize as “old” (Allan & Rugg, 1998; Angel, Fay, et al., 2010; Angel, Isingrini, et al., 2010; Rugg, Fletcher, et al., 1998; Thomson & Tulving, 1970; Tulving & Osler, 1968; Tulving & Thomson, 1973; Tulving & Watkins, 1977), a condition referred to henceforth as a recognition misses for recalled words. Thus, although recall is typically thought to reflect a strong reliance upon explicit, conscious recollection, the existence of recognition misses for recalled words (i.e., recognition failures in recall) suggests that this may not in fact always be the case[2]. This notion is supported by related research on other forms of explicit memory such as familiarity revealing the pervasive ways in which memory processes can be conflated within a given task, and how multiple types of memory can lead to, and hence be mistaken for reflecting, the same type of behavioral response (Bader & Mecklinger, 2017; Lucas, Paller, & Voss, 2012; Ramos, Marques, & Garcia-Marques, 2017; Voss, Lucas, & Paller, 2010; Voss, Lucas, & Paller, 2012).

Despite decades of research, the mechanism that drives the production of misses in these recall paradigms is poorly understood. Accounts of misses generally have focused on explaining how the semantic interpretation of words at study and test could cause recognition processes to fail (see the next section), however no account has yet been put forward to explain why misses are often produced at a level above what would be expected by free-association norms.

[2] For an interesting related phenomenon, see recognition-without-identification (RWI), a finding in which participants have been shown to be able to recognize word-fragment cues of studied words even when they cannot complete the cue itself (i.e., they cannot “recall” the word, Nomi & Cleary, 2012; Ryals, Yadon, Nomi, & Cleary, 2011). In a way, RWI may represent the opposite of misses (which are “recalled” in the absence of recognition).

Thus, although there may be some explanation as to why misses are not recognized, there exists little insight into why they are produced. The goal of the present study is to specifically investigate the underlying processes that drive misses, and to understand the necessary conditions of their production.

By examining established event-related potential (ERP) effects of episodic memory, which have been extensively associated with the processes of priming, familiarity, and recollection (for reviews see Curran, 2000; Friedman & Johnson, 2000; Mecklinger, 2006; and Rugg & Curran, 2007), the present work begins by providing novel electrophysiological data to gain clearer insight into the processes that underlie recall. In particular, this study investigates the degree to which hits and misses in semantic associate cued recall are supported by explicit (recollection, familiarity) versus implicit (priming) retrieval processes. Relative to recall, recognition is often assumed to be more likely to be influenced by implicit processes such as priming (Yonelinas, 2002). However, we aim to show that in quite typical circumstances, recall actually can be similarly driven by both implicit and explicit retrieval processes. Although misses in cued recall have been given limited attention in the past, the neural correlates of recognition misses for recalled words (successful recall followed by recognition failures) have not yet been studied. By investigating the behavioral and neural correlates of recognition misses for recalled words in a forced-recall-recognition paradigm, our goal is to arrive at a clearer understanding of the processes that drive the production of misses in recall tasks generally. Before turning to the current experiments, we provide a more thorough discussion of the issues at hand.

Misses in Recall

The fact that participants occasionally produce misses (i.e., they recall words that they cannot recognize) was a phenomenon of particular interest to cognitive psychologists in the 1960's and 1970's (Thomson & Tulving, 1970; Tulving & Osler, 1968; Tulving & Thomson, 1973; Tulving & Watkins, 1977; for a review, see Gardiner & Nilsson, 1993). Although Tulving and colleagues developed a specific set of procedures to exaggerate this effect[3], and dubbed it the *recognition failure of recallable words*, recognition misses for recalled words (as we label them here) occur routinely in cued recall designs whenever participants are forced both to produce a word on each trial at test and then to recognize that word as "old" or "new" (Allan & Rugg, 1998; Angel, Fay, et al., 2010; Angel et al., 2009; Angel, Isingrini, et al., 2010 ; Rugg, Fletcher, et al., 1998). Indeed, a troubling aspect of misses is that they may be occurring regularly in all recall paradigms but, because they are left unidentified, they ordinarily are interpreted as explicit retrieval. This poses problems for clinical research that relies upon tasks such as recall to make strong inferences about

[3] In Tulving's paradigm, participants studied a set of cue-target pairs at study, in which each target was paired with either a weakly or strongly related semantic associate. At test, participants typically were shown strong semantic associates as cues. It was observed that words studied with weak semantic associates were more likely to be missed than words studied with strong semantic associates. The same effect occurs—as will be shown in the present experiment—in the absence of weakly related semantic associates at study.

neuroanatomical substrates (such as the hippocampus) involved in recall (Ezzyat et al., 2017; Kahana, 2006; Kragel et al., 2017; Yonelinas et al., 2002).

Based on behavioral findings, explanations of why misses are not recognized have asserted that they arise from a semantic mismatch between study and test (Thomson & Tulving, 1970; Tulving & Osler, 1968; Tulving & Thomson, 1973; Tulving & Watkins, 1977). For example, if the word GENERAL was encoded at study in a *military* context, a participant might imagine an army general commanding troops. At test, a participant might receive the cue SPECIFIC and then produce GENERAL in response. Consequently, this test-generated GENERAL would not have the same meaning as the studied GENERAL. Although the two words (GENERAL and GENERAL) are nominally identical, they have completely different meanings ("soldier" and "non-specific"). Thus, they are *not* the same word, and from this semantic perspective there is no reason to assume that a participant should recognize them as the same (Martin, 1975).

Although traditional accounts provide some explanation for why misses are not recognized, these accounts do not elucidate the processes that underlie the generation of misses. Indeed, traditional accounts suggest that misses are simply "happy accidents". Thus, on trials in which the participant is unable to recall the correct studied word, they would be expected to be no more likely to generate the correct studied word to a cue by chance than they would be to produce the "correct" target to a cue that cued an unstudied item. However, misses are often produced to cues more frequently than would be expected by chance, suggesting that some form of fluency (Leynes & Zish, 2012; Leynes & Addante, 2016), explicit familiarity, or perhaps implicit priming must be driving these responses. Unfortunately, neither traditional accounts nor existing behavioral data provide much insight into these underlying processes. In this study, we examined ERP correlates of these processes in order to provide a more thorough investigation of the processes that drive misses.

CHAPTER TWO

EVENT RELATED POTENTIAL CORRELATES

Event Related Potential Correlates of Recollection, Familiarity, and Priming

ERPs have been widely studied in recognition memory research and scientists have been able to characterize distinct spatio-temporal waveforms that can be used as reliable markers of retrieval processes (Addante, Ranganath, & Yonelinas, 2012; Duzel et al., 1997; Friedman & Johnson, 2000; Rugg & Curran, 2007; Rugg, Mark, et al., 1998). Generally, ERPs elicited during recognition tests have been shown to differentiate whether an item has been previously studied (Addante, Ranganath, & Yonelinas, 2012). At a more specific level, however, ERPs also have been used to differentiate specific retrieval processes during memory tests.

Correctly recognized studied items (hits) show an increased positivity compared to correctly rejected new items, a finding dubbed the “old/new effect” (Allan, Doyle, & Rugg, 1996; Allan, Wilding, & Rugg, 1998). This general old/new effect is comprised of at least two temporally, topographically, and functionally distinct components that have been shown to be correlates of explicit memory (i.e., recollection and familiarity) and of implicit memory (i.e., priming). Whereas familiarity is often associated with an old/new difference that onsets relatively early after stimulus onset (~300-500 ms) with a mid-frontal scalp distribution (referred to as a “mid-frontal old-new effect” or “FN400”). Recollection is often associated with an old/new difference, which onsets later (~500-800 ms) and usually with a left parietal distribution, referred to as a parietal old/new effect or "LPC" (Left Parietal Component; Friedman & Johnson, 2000; Rugg & Curran, 2007).

In addition to assessing explicit memory, ERPs are also useful in measuring implicit memory processes. Old/new ERPs associated with priming have been observed to onset early (~300-500 ms), like familiarity, but in contrast are maximally distributed in more posterior scalp regions (Addante, 2015, Addante, Ranganath, Olichney, & Yonelinas, 2012; Addante, Ranganath, & Yonelinas, 2012; Bridger et al., 2012; Li, Mao, Wang, & Guo, 2017; Rugg, Mark, et al., 1998; Yu & Rugg, 2010; Bader & Mecklinger, 2017; although see Voss et al., 2012 and Mecklinger, Frings, & Rosburg, 2012; for differing discussion of these effects[4]). This final point is critical, because behavioral techniques for separating recollection and familiarity do not typically account for implicit memory processes. Indeed, several researchers have recently argued that implicit memory processes may often be mislabeled as familiarity effects, and thereby may distort interpretations of the data (Voss et al., 2012). ERPs offer an additional important benefit in that they potentially allow us to separate explicit from implicit memory processes (Addante, 2015).

[4] As detailed by (Paller, Lucas, & Voss, 2012) and (Mecklinger et al., 2012), there has been some disagreement among researchers concerning the relative contributions of explicit and implicit processing to the mid-frontal ERP effect, particularly in studies using complex stimuli such as faces (Donaldson & Curran, 2007) or geometric shapes (Groh-Bordin, Zimmer, & Ecker, 2006; Voss et al., 2010). However, as described by (Bridger et al., 2012; Mecklinger et al., 2012; Yu & Rugg, 2010), in most cases a reliable topographic dissociation can be observed, and this is particularly true when the stimuli are verbal.

Event Related Potential Correlates of Recall

Although ERPs have been examined extensively in recognition, they have been under-studied in recall. To our knowledge, no ERP studies have investigated cued recall using semantic associates as cues. However, using word-stem cues in forced-recall-recognition paradigms, several studies have begun documenting reliable old/new ERP differences between hits and correct rejections (Allan et al., 1998; Angel et al., 2009; Angel, Isingrini, et al., 2010; Rugg, Mark, et al., 1998), allowing us to draw some inferences and predictions about recall. Nevertheless, ERP studies of recall remain limited and our understanding of recall would benefit from further investigation of its underlying neural processes.

Studies that have examined ERPs in recall and used designs appropriate for comparison with recognition have found results consistent with the recognition studies of recollection-related and familiarity-related ERP effects, although the time windows associated with familiarity and recollection tend to occur slightly later (approximately 200 ms) in recall than in recognition[5]. For example, in their examination of cued recall and source memory, Allan and Rugg (1998) demonstrated that the cued recall old/new effect is composed of a mid-frontal component which onsets 400-700 ms post-stimulus, and a left parietal effect which onsets 800-1200 ms post-stimulus. The posterior effect was associated

[5] This 200-ms delay in recall likely arises because, in recognition tests, test items are presented at the onset of each test trial, whereas in cued recall tests, participants are provided with a cue at the start of each test trial and must take a moment to generate their own candidate for recognition (see Generate-Recognize models of recall, e.g., Haist, Shimamura, & Squire, 1992; Jacoby & Hollingshead, 1990; Nobel & Shiffrin, 2001; Slamecka, 1972).

with the amount of contextual detail retrieved for a given item, which is consistent with the neural correlates of recollection observed for recognition tasks. The earlier anterior effect was also associated with successful retrieval but not with the amount of contextual detail, consistent with the interpretation that it reflects familiarity-based processes.

Similarly, consistent with the recognition correlates of recollection and familiarity, Fay, Isingrini, Ragot, and Pouthas, (2005) demonstrated that an early frontal effect, which onset 400-800 ms post-stimulus, was observed for both shallowly encoded and deeply encoded words in cued recall, but only the deeply encoded words demonstrated a late parietal effect, which onset 800-1100 ms post-stimulus. These convergent recall results suggest that despite both types of items demonstrating a familiarity component, but only those that were deeply encoded showed a recollection component, corresponding with the ERP effects in recognition reported for shallow and deep encoding by Rugg and colleagues (Rugg, Walla, et al., 1998). Thus, ERP results observed in recall appear to closely parallel those observed in recognition, albeit with familiarity and recollection effects onsetting slightly later in recall than in recognition (~200 ms).

With regard to ERP patterns during misses in recall, there is only one published result that provides any relevant analysis. Allan and colleagues (1996) reported that in a word-stem-cued forced-recall-recognition design, although hits showed more anterior positivity than misses or correct rejections (consistent with familiarity occurring for hits but not for misses), misses and correct rejections did not differ. This result could be taken to suggest that no process differentiates misses from correct rejections. It should be noted, however, that Allan et al. did not examine early ERP effects (i.e., < 500 ms after stimulus onset) and therefore their results cannot speak to the hypothesis that misses may be driven primarily by implicit priming processes.

CHAPTER THREE

EXPERIMENTS

Unpublished Data

Recent pilot work by Ozubko et al., (unpublished), used ERPs to explore the specific phenomenon of recognition misses in cued recall paradigms. Participants completed a cued semantic association task in which they first studied a list of several words, and completed a memory test after an ERP cap was applied to the scalp. The memory test consisted of cued semantic associates to each of the words studied earlier, mixed in with a proportion of new words. Participants were instructed to think of a studied word if one came to mind, then to click a mouse button to indicate when they thought of the word (to timestamp an event marker for the ERPs), and then to verbally speak the first word that came to mind, which a researcher nearby would document. Participants were then asked via basic old/new recognition if they recognized the generated word as having been from the study phase of the experiment.

As expected, subjects sometimes missed recognizing words that had been successfully recalled from the study phase, though it remained unclear which cognitive processes was responsible for this phenomenon. When Ozubko et al. assessed the physiological data of ERPs for these data, they found that misses were associated with an earlier posterior activity reminiscent of traditional implicit memory effects (Addante, 2015; Bridger, Bader, & Mecklinger, 2014;

Curran, Tanaka, & Weiskopf, 2002; Rugg, Mark, et al., 1998; Wolk et al., 2004), whereas recognition hits exhibited the traditional ERP markers associated with both familiarity and recollection, respectively (Figure 4 & 5).

While these results are suggestive, this study suffered from several inherent limitations that prevent strong conclusions being drawn from the data. First, the pilot study was limited by a small sample size of participants (N = 22) that reduced to an analyzed sample size of N = 15 when following standard processing procedures of including only subjects with enough valid ERP trials in the core conditions of interest for analysis (Addante, Ranganath, & Yonelinas, 2012; Gruber & Otten, 2010). Furthermore, most of these subjects had insufficient numbers of misses to permit detecting significant differences in these ERP results (typically n > 12 is needed). Since misses were relatively uncommon, subjects did not produce enough of them to yield sufficient data to overcome signal to noise ratio issues in ERP analyses.

Additionally, various other paradigmatic issues could have added unnecessary variance to the ERP data noise, such as the motor activity of the mouse click to record the approximate time when the cued recall occurred. Nevertheless, the Ozubko et al. study provides a potentially useful method by which to explore this poorly understood cognitive phenomenon and offers a base from which to improve upon. The present study aims to overcome these methodological limitations of the Ozubko et al study and bridge the knowledge gap that currently exists regarding the memory processes underlying misses in cued recall.

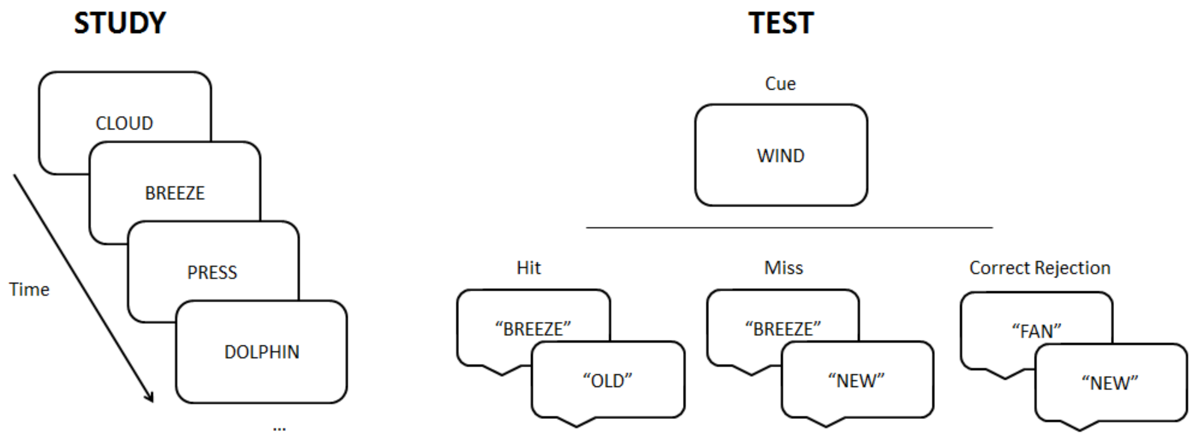


Figure 1. Schematic for Study and Test Phases for Unpublished Data. Schematic of the study and test phases in Ozubko et al. After studying a series of individually presented words, participants were given semantic associate cues and asked to produce a word, either old or new, and to classify it as "old" or "new." Possible outcomes include hits, misses, correct rejections, and false alarms (not depicted; a new item misclassified as "old").

The Present Experiment

Recall is often considered to require a more demanding retrieval process than recognition (Kintsch, 1968, 1970). Consistent with this, words that are recalled are usually also recognized. However, as we have noted, participants occasionally are able to recall words that they cannot recognize. These recognition failures, or misses, represent an interesting paradox in recall. Although theoretical accounts have described how a semantic mismatch between study and test could cause recognition to fail, these accounts do not provide an explanation for the above chance generation of misses. Thus, the specific processes that give rise to misses are unclear.

Electroencephalography (EEG) is often used to investigate memory processes due to its high temporal resolution that can capture neural activity that directly corresponds to specific cognitive processes (Addante, 2015; Addante, Ranganath, Olichney, et al., 2012; Rugg & Curran, 2007), and it can be more sensitive to implicit memory processes than current behavioral methods (Addante, 2015; Berry, Shanks, & Henson, 2008; Blaxton, 1992; Jernigan, Ostergaard, & Fennema-Notestine, 2001; Ostergaard, 1999). Given their sensitivity in differentiating distinct retrieval processes, especially explicit versus implicit influences, ERPs are ideally suited to address the question of which processes give rise to misses of successfully recalled information. Drawing from the ERP literature in recognition memory, we aim to use established ERP correlates of recollection, familiarity, and priming to study semantic-associate cued recall, which to the best of our knowledge has never before been examined using ERPs.

Our goal is to provide new insight into the processes that drive misses in cued recall. In addition, these efforts demonstrate that cued recall ERP effects for hits are consistent with more established frameworks developed from recognition memory, which focus on processes such as recollection, familiarity, and priming. The present experiment tested the prediction that established ERP effects of familiarity and recollection also appear in recall, albeit ~200 ms later than generally observed in recognition. Importantly, the neural correlates of misses have yet to be fully examined in recall. In this research, we aim to provide a clearer understanding of the conditions necessary for misses in cued recall to occur, as well as the underlying cognitive processes involved.

Based on some of the limitations of the Ozubko et al, we designed a follow-up experiment to address these limitations by increasing sample size, increasing the number of trials per participant and increasing the precision of reaction time measures by removing the mouse-click used in the pilot study. The current experiment employed 228 test trials per subject (N = 40) to address the concern about sample size and to increase the number of comparable trials (hits, misses and correct rejections). Additionally, EEG was recorded from 32 scalp sites as opposed to 64 in the pilot study, in order to reduce the time needed to test each subject and to reduce the time needed to improve impedance connections for electrodes, which resulted in better signal to noise ratios.

A modified version of the paradigm designed by Ozubko et al. was used in the present study. We redesigned the paradigm to include a perceptual encoding task instead of simply presenting the study words one at a time. This encoding task required participants to make perceptual decisions (described further in Methods), which provided greater experimental control of the processes or strategies that subjects used to encode the information. The use of a non-semantic task served to mitigate elaborative encoding processes that improve memory performance and beneficially increased the occurrence of the “miss” condition we are investigating. Furthermore, the 4x study-test format used previously by Ozubko et al. was replaced by a design in which all study sessions are presented first and all test sessions afterwards. This avoided possible primacy and recency effects in working memory, and thereby also increased the occurrence of ‘miss’ trials needed for proper analysis of our hypotheses. The testing procedure remained largely the same as that used by Ozubko and colleagues (Figure 1), with the added integration of a voice key, that recorded participants’ verbal responses precisely when recall occurred and that effectively eliminated the additional motor activity of having to click a mouse key when a response came to mind.

CHAPTER FOUR

METHODS

Participants

Forty right-handed undergraduate students were recruited to participate in exchange for monetary compensation of $10/hr. Participants were identified through screening processes as normatively healthy, free from any neurological disorders, fluent English speaking, and right-handed. Handedness was assessed via an Edinburgh handedness inventory, and other demographic criteria were established via self-reporting questionnaires.

Materials

The same stimuli were used in this current study as were used by Ozubko et al. A word pool of 200 cue-target pairs was created from the free association norms of Nelson, McEvoy, and Schreiber (2004). For present purposes, the backward association norms compiled by Nelson et al. were of principal interest. These norms are arranged by target words instead of cue words: For each target word, the norms provide a list of the cue words that give rise to that target word with the probability that each cue word will give rise to that particular target word. For example, if "RIGHT" was the target word of interest, Nelson et al. list *left*, *wrong*, *correct*, and *accurate* as cue words which give rise to RIGHT during free association, with probabilities of .93, .72, .23, and .16, respectively. Note that for our purposes, cases of repetition either between the target and cues or within the cues of different items are eliminated. For example, if PRINCESS was a target itself but *princess* was also a cue for the target KING, then one of these items would be eliminated to avoid repetition. Additionally, if *universe* were a cue for the target word WORLD but also for the target word GALAXY, then one of these items would be eliminated. We used the strongest associate of each target as its cue. On average, the normed probability that the strong associate cues would give rise to their respective target words is .58 (SD = .13).

EEG was recorded during the test phase using a 32-channel EEG system (Brain Vision's ActiCHamp design http://www.brainvision.com/actichamp.html) of Ag-CL electrodes un-referenced, at 500 Hz sample rate. This montage includes pre-amplifiers built into each electrode and electrically-shielded cabling. EEG sites were prepared and abraded with saline gel to facilitate optimal signal to noise connections with scalp sites in accord with the international 10-20 system (Klem, Luders, Jasper, & Elger, 1999). Available cap sizes ranged from 42-60 cm to accommodate participant variability. The electrode sites on the cap were filled with electrode gel prior to insertion of the active electrodes. After insertion of active electrodes, impedance was reduced via gentle abrading of each site. Participants were instructed to minimize muscle tension, eye movements, and blinking during the test sessions. Electrooculogram (EOG) was monitored in the horizontal (lateral to each eye) and vertical directions (below and above the left eye) to eliminate trials contaminated by blink or eye-movement artifacts. Electrodes were washed after each participant, and caps disinfected to minimize risk of disease transmission. An SV-1 Voice Key was used for logging precise voice responses during EEG recording of memory recall. The SV-1 is a device designed specifically for experiments requiring a vocal response and monitored the participant's voice level at all times. When the voice level rose above a user-specified threshold, the device reported this to the computer recording the EEG timestamps. The SV-1 is powered by an 18 MHz microprocessor and is a 100% digital device.

Procedure. Upon arrival, participants were given a brief description of the experiment and were shown the electrophysiological equipment and how it would be used. Participants were then instructed to complete all consent forms, demographic questionnaires and the Edinburgh Handedness Inventory. Instructions on task performance were read from a prepared script and reminders were given periodically. Short practice runs were used to ensure that instructions were understood and that the participants were responding correctly. The experiment consisted of 144 words during the study phase, broken down into 6 study- blocks with 24 words per block. The test phase consisted of 288 words, divided into 6 blocks of 48 words per block. Half of the words presented in each test session were semantic associate cues for the previously studied words and the other half were new words. These two types of trials were randomly inter-mixed at test and participants were explicitly informed that some cues would be more useful than others for retrieving studied words. Stimuli for both the study and test phases were randomly selected for each participant.

In the study phase (Figure 2), participants first encoded a word presented on the screen for 1s and then were asked to indicate whether the font-color of the presented word was white or grey, as indicated by pressing a response button corresponding to the location of grey and white boxes on the screen. As a perceptual distractor meant to not facilitate encoding, these boxes randomly alternated order, while the response keys “Grey” and “White”, remained in the same location.

The retrieval test (Figure 3) began with a fixation cross which appeared for a variable duration of 1000, 1500 or 2000ms. Next, a semantic associate of a studied word or a new word was presented on screen for 1 s and then automatically followed by the recall prompt screen. Participants were instructed to think of a studied word in response to the test cue or, if a studied word did not come to mind, to think of any new word. Participants were instructed to speak the recalled word aloud as soon as it comes to mind. The voice key device recorded the response time and integrated this event code into the EEG data. Immediately after their verbal response, participants were then prompted with an old-new recognition task and asked to identify the word that they produced as either “old” (from the study session) or “new” (not from the study session). To avoid introducing noise from eye-blinks into the neural data, participants were instructed not to blink when probes were on the screen, and to only blink during the ‘Rest’ screen, which indicates it is OK to blink (Addante et al., 2011).

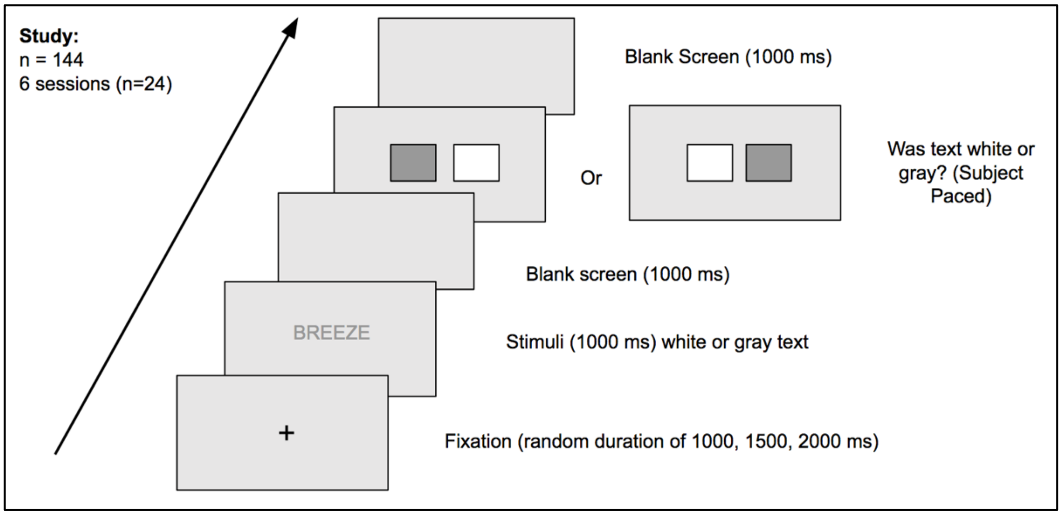


Figure 2. Study Paradigm. A total of 144 words, divided into 6 blocks of 24 words, were presented one at a time. Participants were instructed to select the color of the word, represented by gray and white boxes that alternate positions on the screen.

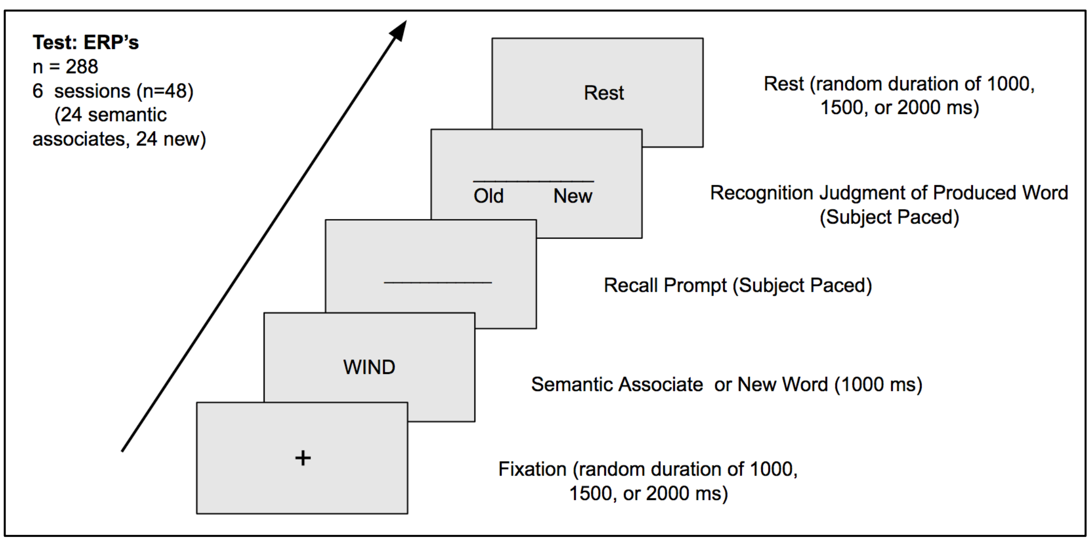


Figure 3. Test Paradigm. Two-hundred and eighty-eight new words, split into 6 blocks of 48 words, were presented one at a time, followed by a recall prompt. Half of the words were semantic associates from the study session and the other half were non-associate new words. Participants were prompted to recall the first word from the study session that came to mind, and then to recognize that word as “old” (from the study session) or “new” (not from the study session).

CHAPTER FIVE

DATA ANALYSIS

Participants' responses on the memory test were assessed for accuracy and reaction time and analyzed using two-tailed t-tests between conditions of interest (hits vs misses, hits vs correct rejections, and misses vs correct rejections). Participants performing below chance levels on the memory test were excluded from analysis. EEG data was analyzed using EEGLab (Delorme & Makeig, 2004) and ERP Lab analysis toolboxes (Lopez-Calderon & Luck, 2014) for Matlab software.

EEG Data was re-referenced offline to the average of the left and right mastoid electrodes, then baseline corrected to the average activity 200ms pre-stimulus by a polynomial detrending function of zero using a .1 Hz high pass filter, and down sampled to 256 Hz. The data was then epoched beginning 200ms pre-stimulus presentation through 1800ms post-stimulus presentation. This is the entire duration of when each item was presented to the participant and was categorized for analysis based on the subsequent responses given for recall and recognition. Independent components analysis (ICA) was performed using InfoMax techniques in EEGLab (Bell & Sejnowski, 1995) to accomplish artifact correction and then resulting data was individually inspected for artifacts, rejecting trials for eye blinks and other aberrant electrode activity. During ERP averaging, trials exceeding ERP amplitudes of +/- 250 mV were excluded.

Additional filtering, such as a 30hz low pass filter, was applied to group ERPs in order to make figures correspond to the similar ‘smoothing’ function that the standard process of taking the mean voltage between a given two latencies accomplishes during statistical analyses of results.

Using the ERPLAB toolbox (Lopez-Calderon & Luck, 2014), automatic artifact detection for epoched data was also used to identify trials exceeding specified voltages, in a series of sequential steps as noted below. Simple Voltage Threshold identified and removed any voltage below -100ms. The Step-Like Artifact function identified and removed changes of voltage exceeding a specified voltage (100uV in this case) within a specified window (200ms), which are characteristic of blinks and saccades. The Moving Window Peak-to-Peak function is commonly used to identify blinks by finding the difference in amplitude between the most negative and most positive points in the defined window (200ms) and comparing the difference to a specified criterion (100 uV). The Blocking and Flatline function identified periods in which the voltage did not change amplitude within a specified window (848ms). An automatic blink analysis, Blink Rejection (alpha version), used a normalized cross-covariance threshold of 0.7 and a blink width of 400ms to identify and remove blinks (Luck, 2014).

For statistical analysis, we computed the mean amplitude of the ERPs across designated time windows at each electrode site for each participant and condition, and then assessed for reliable differences between the average of each respective condition. As mentioned in the introduction, the time windows associated with familiarity and recollection tend to occur slightly later (approximately 200 ms) in recall than in recognition because in cued recall tests, participants are provided with a cue at the start of each test trial and must take a moment to generate their own candidate for recognition (see Generate-Recognize models of recall, e.g., Haist, Shimamura, & Squire, 1992; Jacoby & Hollingshead, 1990; Nobel & Shiffrin, 2001; Slamecka, 1972). Due to the more demanding nature of recall, the time windows we identified for familiarity and recollection are approximately 300 ms later than identified in other studies using different retrieval tasks (Ozubko, Ahmad, Addante, & Macleod, unpublished). For the familiarity contrast we focused on the 600-900ms time period at mid-frontal electrode sites, whereas for the recollection contrast we focused on the 900-1100 ms time window at parietal electrode sites. These time windows and electrode sites were selected a priori based on other studies of familiarity and recollection that identify time windows of 300-500ms and 600-800ms, respectively for each. (Addante, Ranganath, Olichney, et al., 2012; Addante, Ranganath, & Yonelinas, 2012; Leynes, Landau, Walker, & Addante, 2005; Rugg & Curran, 2007). Implicit memory effects were assessed by creating a posterior electrode cluster of parietal and occipital electrodes during the 300-500ms time window, consistent with prior studies' characterization of implicit memory effects (Addante, 2015; Bader & Mecklinger, 2017; Bridger et al., 2012; Li, Mao, et al., 2017; Li, Taylor, et al., 2017; Mecklinger et al., 2012; Rugg, Fletcher, et al., 1998; Strozak, Abedzadeh, & Curran, 2016; Voss et al., 2012; Voss & Paller, 2007; Voss & Paller, 2017; Yu & Rugg, 2010). Direct contrasts were assessed using corrected t-tests to assess differences between memory conditions.

CHAPTER SIX

HYPOTHESES

We analyzed ERPs for three main conditions representing the combination of recall and recognition responses given by participants: Hit_Hits, Hit_Misses, and correct rejections. We hypothesized that explicit memory processes of familiarity and recollection would be evident in contrasting hits to correct rejections at mid-frontal scalp sites from 600-900ms and at parietal sites from 900-1100ms, respectively (Figures 4 & 5). These explicit memory processes were predicted to exhibit a delayed onset shift by roughly 300 milliseconds from the traditional latencies evident in recognition memory due to the extra processing time needed for search process in recall, consistent with the extant literature reviewed above.

Critically, we hypothesized that instances of Hit_Misses would show evidence of implicit memory processing as reflected by posterior activity occurring from 300-500ms when compared to correct rejections (Figure 4 & 5). The implicit effects were predicted to remain relatively early since their inherent automaticity should have remained unaffected by the search demands of recall. These predictions were based upon existing theoretical models of memory physiology and would converge with the preliminary results from Ozubko et al., which showed a similar pattern of effects that were not statistically reliable. These findings would converge with those of Ozubko et al., in suggesting three main conclusions: (1) standard measures of cued recall can be contaminated by implicit memory, (2) treating cued recall responses as a relatively straightforward measure of explicit memory is not always appropriate, and (3) recall and recognition have more in common at a process level than is routinely acknowledged. Alternatively, if the Hit_Miss conditions exhibited the FN400 or LPC, this would be taken as evidence of explicit memory processes of familiarity and recollection, respectively. In either case, the results would provide important evidence for identifying the cognitive processes underlying recognition failures for successfully recalled information.

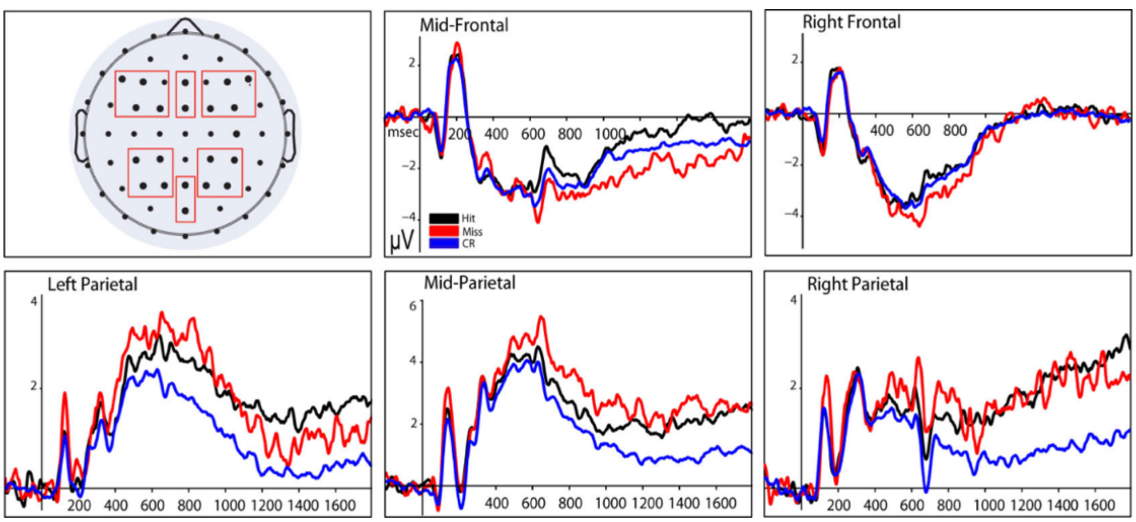


Figure 4. Unpublished Event Related Potential Activity for Hits, Misses, and Correct Rejections. Unpublished data by Ozubko et al. showing mean ERP activity for hits, misses, and correct rejections in left, mid, and right frontal and parietal regions.

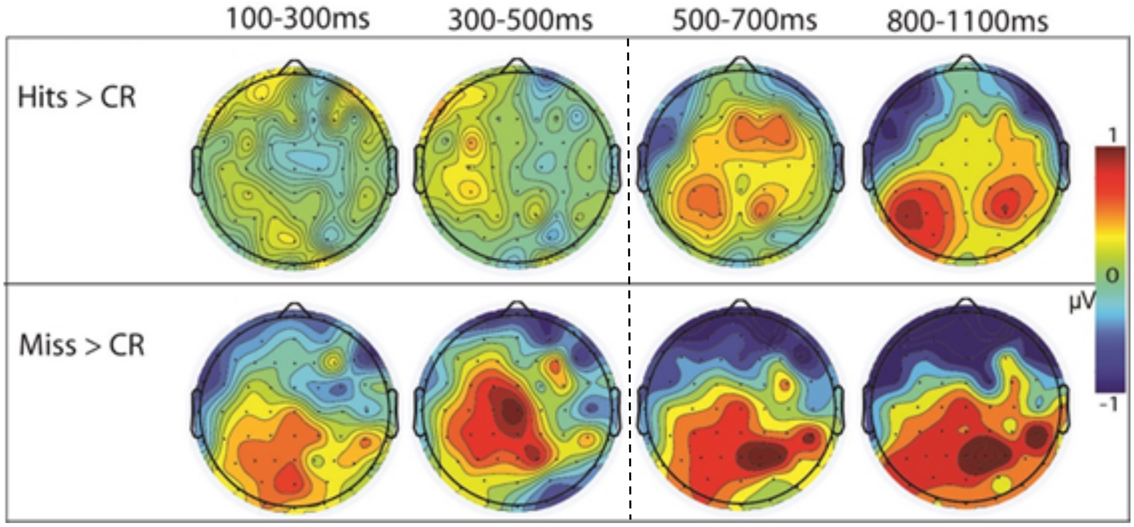


Figure 5. Unpublished Topographic Maps of Implicit and Explicit Memory.
Presumed implicit (left of dashed line) and explicit (right of dashed line) memory effects from Ozubko et al.

CHAPTER SEVEN

RESULTS

The primary goal of the current study was to assess the replicability of the preceding work conducted by Ozubko et al. as noted in the Introduction, using a larger sample size and a more refined study paradigm. In their analyses, Ozubko and colleagues defined “hits” as any instance in which an old word was produced at recall and later recognized as old, regardless of whether or not a semantic associate cue was given to the participant. By this definition of hits, they collapsed across semantic associate and non-semantic associate conditions, failing to distinguish whether the participant produced merely ‘any’ old word from the study phase or if they produced specifically the target old word for a given semantic pairing. (e.g. the participant produces “Animal” instead of “Stripe” to cue the word “Zebra”, where “Animal” is an old word but “Stripe” is the target word (Supplemental Figure 1).

Accordingly, Ozubko et al (unpublished) defined “misses” as instances in which an old word was produced at recall and the participant incorrectly identified the word as “new” for the recognition judgment. Like hits, misses were also not separated by whether a semantic associate or non-associate cue was given. Similarly, Ozubko and colleagues defined correct rejections as instances in which new words were produced at recall in response to either a semantic associate or non-associate cue and then also correctly identified the word as being new at recognition [6]. The conditions Ozubko originally compared will be referred to as "Collapsed Associate Conditions" (CAC).

We reasoned that Ozubko's procedure was a good start for preliminary analysis, but may also be obscuring certain neurophysiological effects in ERPs due to collapsing across disparate conditions, and thus we sought to create a more targeted analysis. Therefore, we used more specific criteria for defining hits, misses and correct rejections. In particular, the present experiment separated recall hits in which participants produced the target word ("OldPair") from trials in which participants instead produced any old word from the study phase ("OldAny"). These conditions will be referred to as "Specified Associate Conditions" (SAC).

For the Specified Associate Conditions analyses, only hits and misses that resulted from semantic associate cues, and correct rejections from non-associate cues were analyzed. "Hits" were defined as instances in which participants *produced the target old word in response to a semantic associate cue*, and then also went on to successfully rate the word they produced as being 'old' (later referred to in more detail as "S_OldPair_Hit"). "Misses" were defined as instances in which participants *produced the target old word in response to a semantic associate cue* and then misidentified the word they produced as a 'new' word (later referred to in more detail as "S_OldPair_Miss"). For the Specified

[6] This condition represents a control condition (or a "no memory" condition from which to compare other memory conditions to) because the subjects do not indicate any memory of a studied word in this condition.

Associate Condition, only hits and misses that were produced from semantic associate cues were analyzed. Hits and misses resulting from non-associate cues were excluded in this analysis, but they were included in the Combined Associate Condition. “Correct rejections” were accordingly defined as new words *produced in response to non-associate cues*, which were then correctly identified as new words (later referred to in more detail as “N_New_CR”). This version of correct rejections differs from the correct rejection condition examined by Ozubko and colleagues because new words produced in response to semantic associate cues were not examined in this condition. This is because we did not want to contaminate this “no memory” condition with a semantic associate cue, which may potentially initiate any kind of memory process that was not subjectively reported by the subject.

Behavioral results were analyzed first and then followed by analysis of electrophysiological results. An alpha level of .05 was used as the criterion for all significance tests and reaction times (RT’s) are reported in milliseconds.

Behavioral Results

Recall Accuracy

Of the 288 test trials per participant, participants produced a valid response (a coherent, non-repeated word) 82% of the time during cued recall (M = 236 trials, SE = 4.64). Of these valid responses, an old word from the study phase was produced, on average 32% of the time (M = 76, SE = 2.96), while

68% of the produced items were new words, which had not been studied (M= 160, SE = 3.97, Figure 6 & Table 1). Of the old items produced at recall, an average of 30% were pairs to the target words shown at the study phase ("OldPair", M = 71, SE = 3.24) and only 2% were old words which were not the paired to the target words ("OldAny", M = 5, SE = .66). These results largely mirror those reported previously by Ozubko et al., and demonstrate that our enhanced paradigm was successful at replicating the core patterns of behavioral responding by participants across studies.

Recognition Accuracy

Of the old items produced during recall, 59% went on to be correctly recognized as 'old' ("Hit_Hits"; M = 45, SE = 3.20). For these hits, the probability that it was a cue-target match during recall was 94% (SE = .01). Accordingly, 31% of old items were incorrectly identified as 'new' ("Hit_Misses"; M = 31, SE = 2.45). Recognition misses had a probability of 92% (SE = .02) for being a cue-target match during recall.

At recognition, new items that were produced during recall could either be correctly identified as 'new' ("New_CRs") or be incorrectly identified as 'old' ("New_FAs"). Overall, of the new words produced at recall, 73% were correct rejections (M = 117, SE = 7.89), and 27% were false alarms (M = 43, SE = 5.71; Figure 8, Table 2). Ozubko and colleagues had previously found reliable differences between the reaction times of hits and misses, as well as between hits and correct rejections; the current data replicate both these findings as well as the significant differences between other conditions that are discussed in the subsequent section below.

Recall Response Times

Ozubko and colleagues did not report reaction times (RT) for recall responses (i.e. how long it took participants to produce a word) because this onset was recorded by mechanical button presses and hence not precisely measurable in that study (a limitation that is similar for nearly all extant EEG studies of recall); however, in the current study we had the ability to precisely measure this variable as it was recorded by a digital voice response detector (see Methods). We thus investigated response times for the recalled items because it could potentially shed light on the processes used for producing an old or new word in recall. Recall responses that were targets paired with the study words (“Old Pair”; M = 1062, SD = 268.20) were produced reliably faster than old items that were not paired with the target (“Old Any”; M = 1408, SD = 687.86), t (14) = -2.17, p <. 05, and were also produced faster than new words (M = 1779, SD = 703.01), t (14) = -5.78, p <. 001. RTs for the “Old_Any” condition did not reliably differ from new words, p > .05 (Figure 7 & Table 1).

Recognition Response Times

In the current study, recognition RTs were measured by the participant's button response indicating the produced word was old or new (see Methods). For recognition responses, hits (M = 936, SD = 381.74) were reliably faster than misses (M = 1099, SD = 394.49), t (14) = -3.33, p < .01, as well as correct rejections (M = 1140, SD = 404.34), t(14) = -4.47, p < .001 (Figure 9 & Table 2). Misses were not significantly different from false alarms or correct rejections.

Combined Condition Response Times

Since part of our hypothesis particularly (and importantly) focused upon combinations of recall and recognition memory patterns, we also measured the RTs for these various combinations of memory responses. For each combined condition, there is a reaction time for the recall portion and a reaction time for the recognition portion (Figure 11 & Table 3).

The recall reaction times for combined conditions of OldPair words that went on to become hits at recognition ("SemAs_OldPair_Hit", M = 946, SD = 56.21) were found to be reliably quicker than the OldPair words than went on to be missed at recognition ("SemAs_OldPair_Miss", M = 1233, SD = 109.30; t (14) = -3.38, p = .002), as well as new words that went on to be incorrectly rated as old ("Non_SemAs_New_FA", M = 1669, SD = 208.74; t (14) = -4.05, p = .0006) and new words that went on to be correctly identified as new at recognition ("Non_SemAs_New_CR", M = 1790, SD = 170.06; t (14) = -5.97, p = .00002).

OldPair items that later went on to become misses were also reliably faster than New words that later went on to be incorrectly recognized as old ("Non_SemAs_New_FA", $t(14) = -2.78$, $p = .007$), and correct rejections ("Non_SemAs_New_CR", $t(14) = -6.92$, $p = .000004$; Figure 10 & Table 3).

The recognition portion of these combined conditions also were found to reveal significant RT differences. Hits ("SemAs_OldPair_Hit", $M = 930$, $SD = 98.68$) were reliably faster than both misses ("SemAs_OldPair_Miss", $M = 1098$, $SD = 96.81$, $t(14) = -3.17$, $p = .003$), false alarms ("Non_SemAs_New_FA", $M = 1107$, $SD = 125.04$; $t(14) = -3.37$, $p = .002$) and correct rejections ("Non_SemAs_New_CR", $M = 1140$, $SD = 108.28$; $t(14) = -4.49$, $p = .0003$; Figure 12 and Table 3).

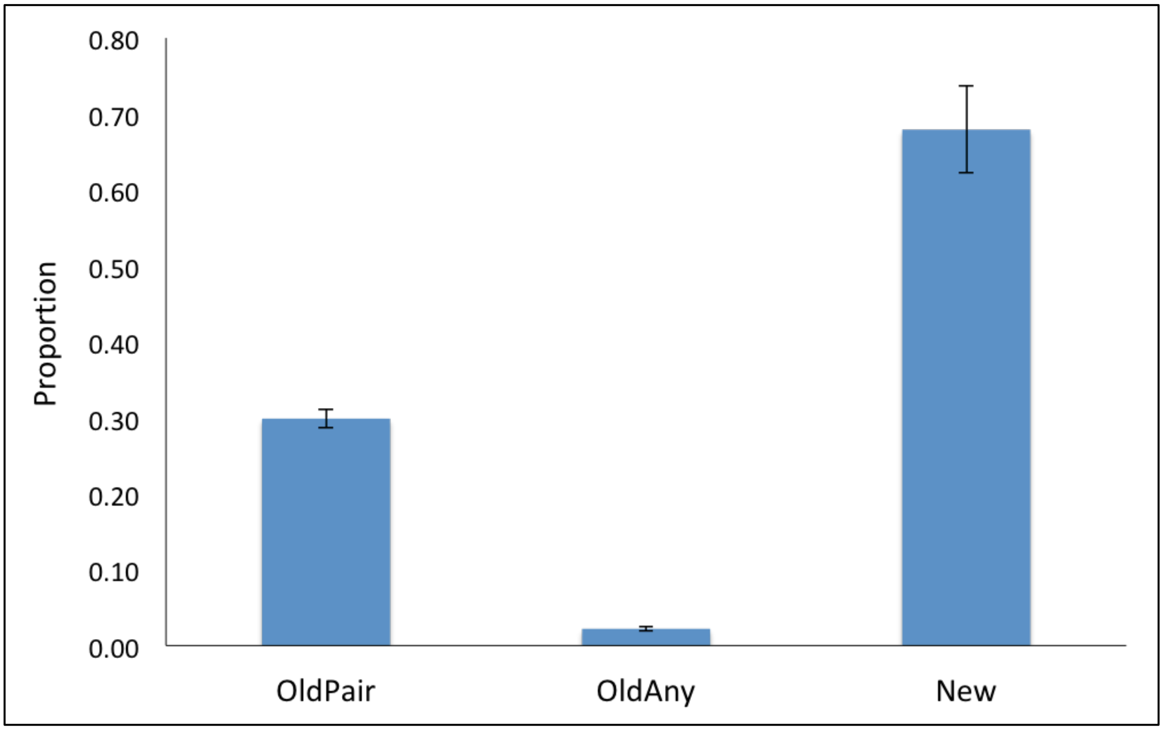


Figure 6. Response Distributions for Recall Judgments. At recall, participants produced either an old word from the study phase that was the target pair to the prompt (“OldPair”), an old word from the study phase that was not the target pair to the recall prompt (“OldAny”), or a new word that was not from the study phase (“New”).

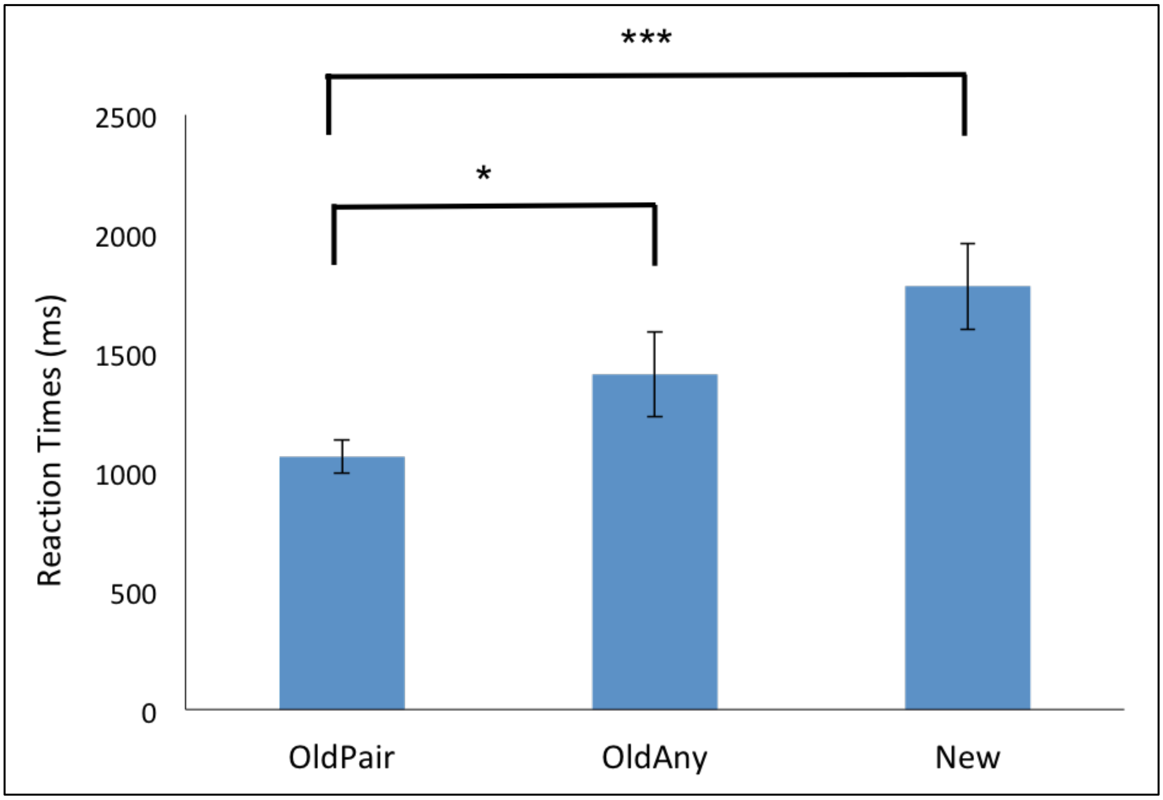


Figure 7. Reaction Times for Recall Judgments. At recall, participants produced either an old word from the study phase that was the target pair to the prompt ("OldPair"), an old word from the study phase that was not the target pair to the recall prompt ("OldAny"), or a new word that was not from the study phase ("New"). * $p < .05$, *** $p < .001$

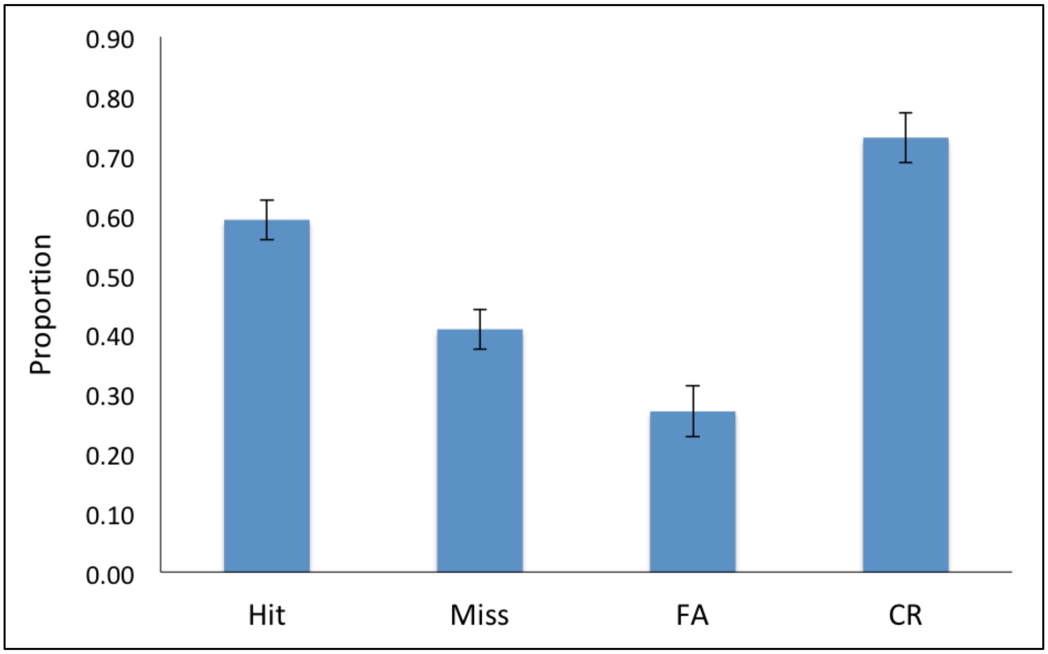


Figure 8. Recognition Response Distributions.

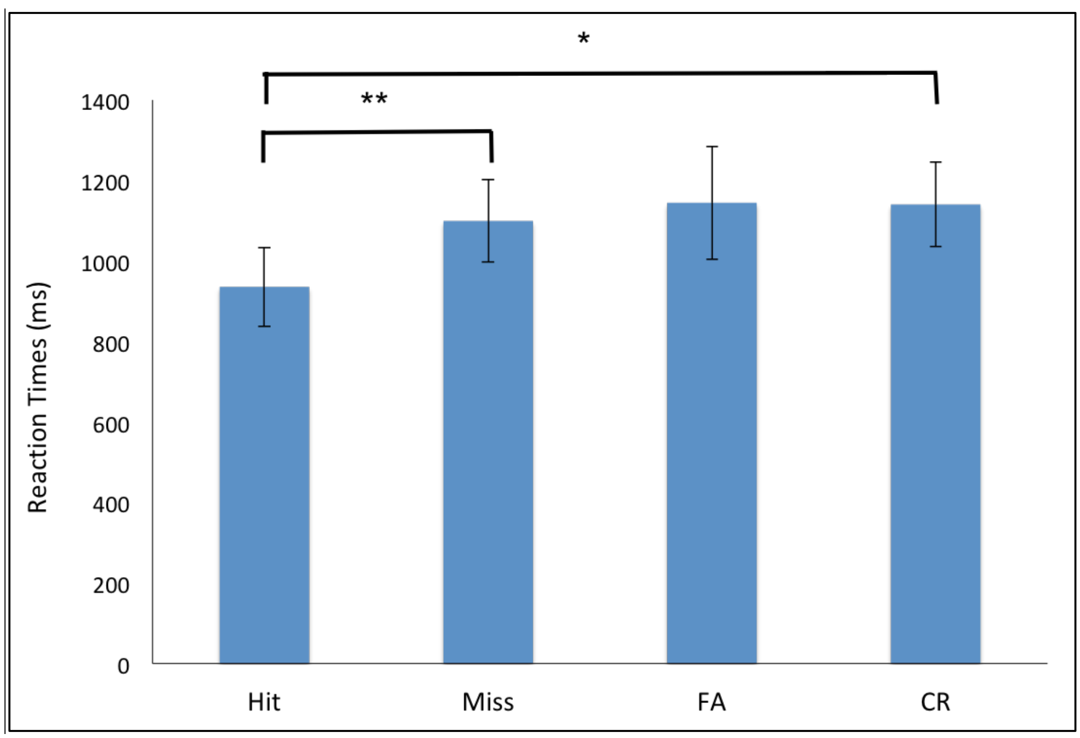


Figure 9 Reaction Times for Recognition Judgments. Correct rejections (CR) and False Alarms (FA). * p < .05, ** p <.01

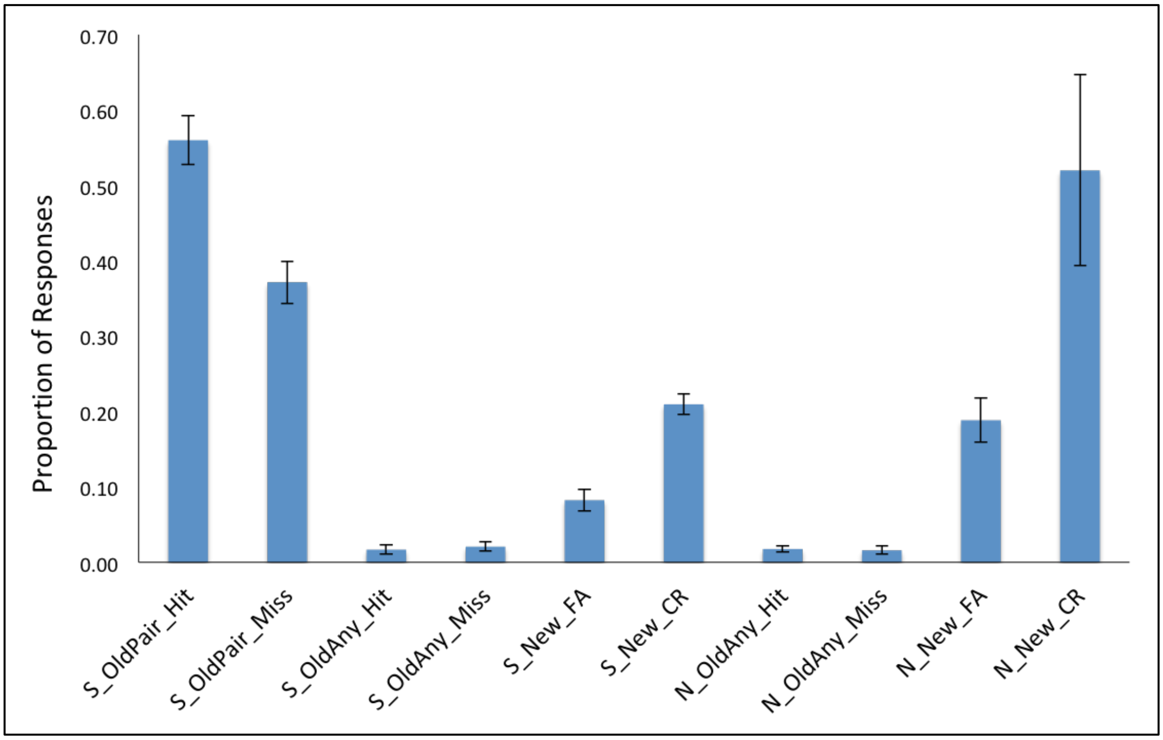


Figure 10. Combined Recall and Recognition Response Distributions. Each underscored condition name on the x-axis represents three pieces of information. The first piece of information indicates whether the word presented at the recall prompt was a sematic associate cue ("S") or a non-associate cue ("N"). The second piece of information indicates whether at the recall prompt, the participant produced and old word that was a pair to the target ("OldPair"), any old word from the study phase ("OldAny"), or a new word that was not from the study phase ("New"). The third piece of information indicates what category of response was given at the recognition prompt (hit, miss, correct rejection (CR), or false alarm (FA)).

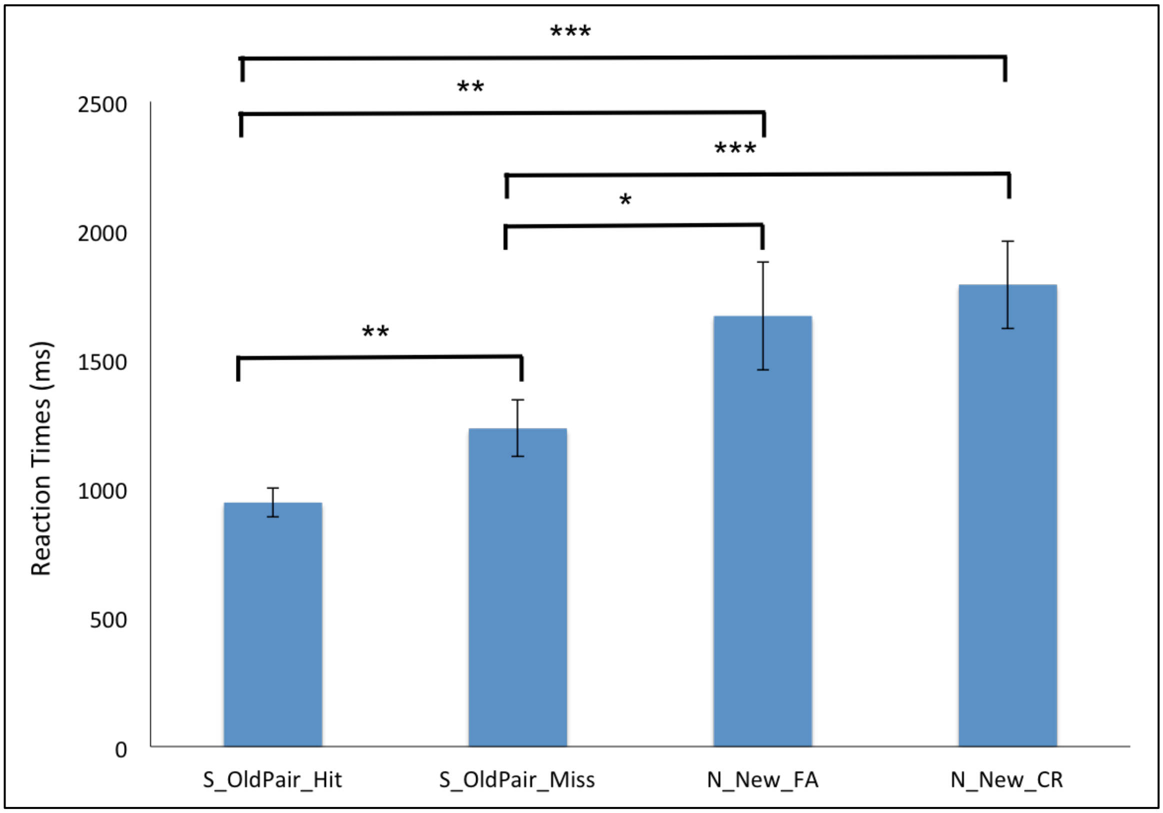


Figure 11. Reaction Times for Combined Recall and Recognition Conditions for the Recall Response of each Combined Condition. Each underscored condition name represents three pieces of information. The bars in this graph represent reaction times from the second piece of information (recall response). The first piece of information indicates whether the word presented at the recall prompt was a sematic associate cue ("S") or a non-associate cue ("N"). The second piece of information indicates whether at the recall prompt, the participant produced and old word that was a pair to the target ("OldPair"), any old word from the study phase ("OldAny"), or a new word that was not from the study phase ("New"). The third piece of information indicates what category of response was given at the recognition prompt (hit, miss, correct rejection (CR), or false alarm (FA)).

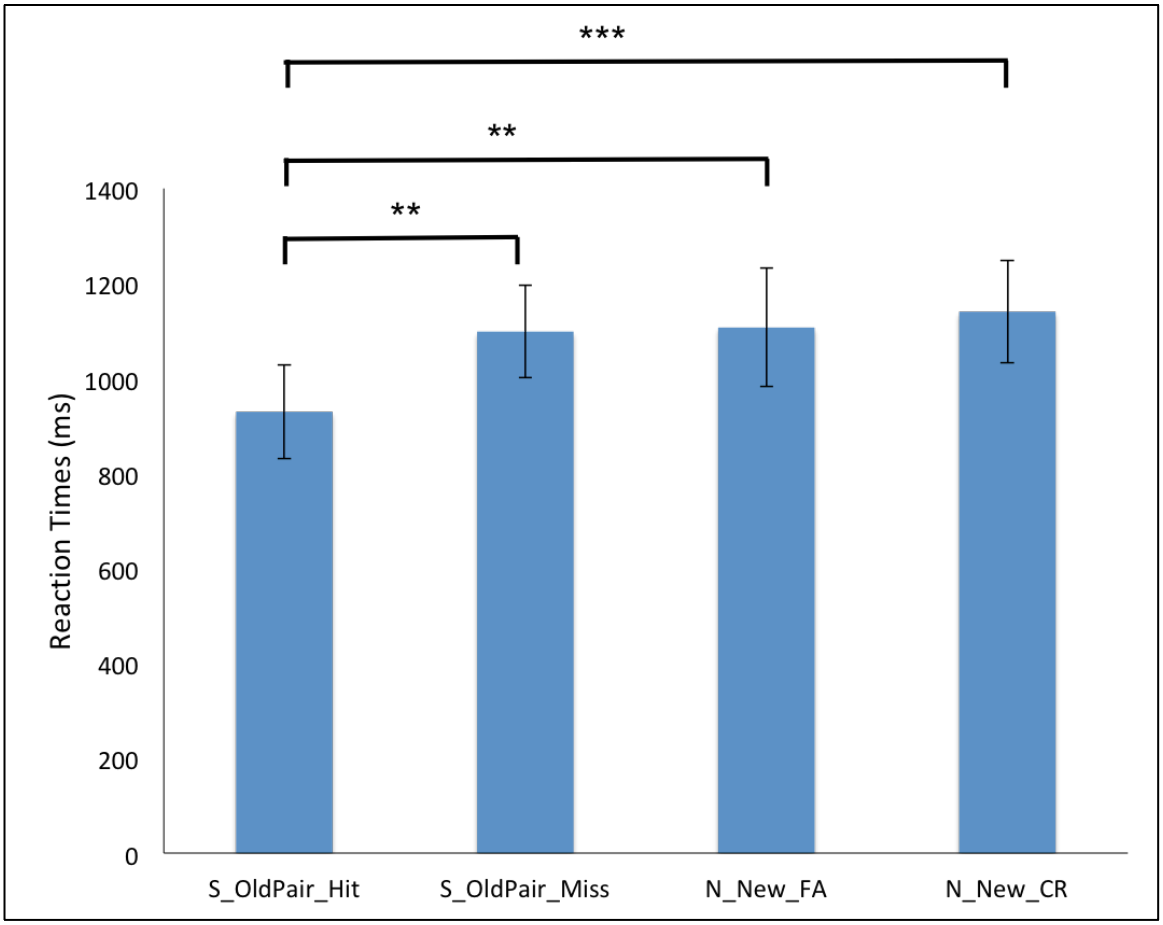


Figure 12. Reaction Times for Combined Recall and Recognition Conditions for the Recognition Response of each Combined Condition. Each underscored condition name represents three pieces of information. The bars in this graph represent reaction times from the third piece of information (the recognition response). The first piece of information indicates whether the word presented at the recall prompt was a sematic associate cue (“SemAs”) or a non-associate cue (“NonAs”). The second piece of information indicates whether at the recall prompt, the participant produced and old word that was a pair to the target (“OldPair”), any old word from the study phase (“OldAny”), or a new word that was not from the study phase (“New”). The third piece of information indicates what category of response was given at the recognition prompt (hit, miss, correct rejection (CR), or false alarm (FA)).

Table 1. Recall Responses. Standard errors are listed in parentheses.

Recall Responses	Avg. Number Responses	Proportion	Reaction Time (ms)
Valid Response	236 (4.64)	.82 (.02)	1417 (120.22)
Old Pair	71 (3.24)	.30 (.01)	1062 (69.25)
Old Any	5 (.66)	.02 (.00)	1408 (177.60)
New	160 (3.97)	.68 (.01)	1779 (181.52)

Table 2. Recognition Response Categories. Standard errors are listed in parentheses.

Recognition Response	Avg. Number of Responses	Proportion	p(cue-target match)	Reaction Time (ms)
Hit	45 (3.20)	.59 (.03)	.94 (.01)	1016 (108.06)
Miss	31 (2.45)	.41 (.03)	.92 (.02)	1110 (125.03)
CR	117 (7.89)	.73 (.04)	N/A	1139 (101.58)
FA	43 (7.34)	.27 (.04)	N/A	1131 (136.44)

Table 3. Combination Patterns of Recognition Conditions. Standard errors are in parentheses. For the second column, the first piece of information indicates whether the word presented at the recall prompt was a sematic associate cue (“SemAs”) or a non-associate cue (“NonAs”). The second piece of information indicates whether at the recall prompt, the participant produced and old word that was a pair to the target (“OldPair”), any old word from the study phase (“OldAny”), or a new word that was not from the study phase (“New”). The third piece of information indicates what category of response was given at the recognition prompt (hit, miss, correct rejection (CR), or false alarm (FA)).

Response	Condition Detail	# of Responses	%	*p*(cue-target match)	Recall RT (ms)	Recognition RT (ms)
Hit_Hit	SemAs_OldPair_Hit	42 (3.15)	.56 (.03)	.97 (.01)	946 (56.21)	930 (98.68)
	SemAs_OldAny_Hit	1 (.38)	.02 (.01)	NA	1276 (317.92)	684 (56.49)
	NonAs_OldAny_Hit	1 (.30)	.02 (.00)	NA	1233 (286.39)	1282 (184.17)
Hit_Miss	SemAs_OldPair_Miss	28 (2.30)	.37 (.03)	.95 (.01)	1233 (109.30)	1098 (96.81)
	SemAs_OldAny_Miss	1 (.40)	.02 (.01)	NA	2042 (409.75)	1252 (230.52)
	NonAs_OldAny_Miss	1 (.38)	.02 (.01)	NA	1269 (190.39)	897 (94.92)
New_CR	SemAs_New_CR	34 (2.76)	.21 (.01)	NA	2127 (312.74)	1137 (96.76)
	NonAs_New_CR	83 (5.70)	.52 (.03)	NA	1790 (170.06)	1140 (108.28)
New_FA	SemAs_New_FA	13 (2.54)	.08 (.01)	NA	1670 (256.67)	1154 (166.78)
	NonAs_New_FA	30 (5.00)	.19 (.03)	NA	1669 (208.74)	1107 (125.04)

Electrophysiological Results

ERP results are presented for each electrode region in temporal sequence through the epochs identified from our hypotheses based upon the existing literature (see Introduction and Methods), starting with earliest latency (100-300ms) and progressing through each subsequent period (300-500ms, 600-900ms and 900-1100ms). The same conditions were compared as were examined previously by Ozubko et al (i.e. recalled items that received a recognition hit, versus those which received a recognition miss, and versus correct rejections), and then followed up with our more specific conditions in subsequent sections. For each time period, ERP effects are presented in order of our conditions of interest: hits and misses, with each contrasted against correct rejections. Paired two-tailed t-tests were used to compare conditions for each electrode cluster of regions during the a-priori defined latencies.

Electrode clusters were created for each hemisphere and region, based upon the international 10-20 system (Klem et al., 1999). The left frontal cluster included sites F3, F7 and FC5; mid frontal included sites Fz, FC1 and FC2; and the right frontal cluster comprised sites F4, F8 and FC6. Accordingly, the left parietal cluster included sites CP5, P3 and P7; mid parietal included Pz, CP1 and CP2; and the right parietal cluster comprised CP6, P4 and P8. In order to maintain sufficient signal-to-noise ratio (SNR), all comparisons relied upon including only those subjects who met a criteria of having a minimum of 12 artifact-free ERP trials per condition being contrasted (Addante, Ranganath, &

Yonelinas, 2012; Gruber and Otten, 2010; Kim et al., 2009; Otten et al., 2006; c.f. Luck 2016). For our main analysis this yielded a sample of 31 participants, and the sample sizes for our subsequent analyses that met this criteria are indicated in each of those sections, respectively.

Recall Results for Collapsed Associate Conditions

100-300ms. Hits (M = 1.47, SD = 2.16) were marginally greater than misses (M = 1.83, SD = 2.07) at the right frontal region t (30) = -1.97, p = .06, and misses (M = 1.83, SD = 2.07) were also found to be marginally greater than correct rejections (M = 1.460, SD = 1.77) at right frontal electrodes, t (30) = 1.96, p = .06 (Figures 13 & 14).

300-500ms. Hits (M = -0.57, SD = 2.90) were reliably more negative than misses (M = 0.01, SD = 2.95) at right frontal sites (t (30) = -2.17, p = .04).

600-900ms. Hits (M = .56, SD = 2.45) were marginally more positive than correct rejections (M = .24, SD = 2.43), at right parietal electrodes (t (30) = 1.91, p = .07)

900-1100ms. In the mid parietal region, hits (M = 1.05, SD = 2.93) were more positive than correct rejections (M = 0.33, SD = 3.04), t (30) = 2.50, p < .05. Likewise, in the right parietal region, hits (M = 0.48, SD = 2.19) were more positive than correct rejections (M = -0.14, SD = 2.34), t (30) = 3.29, p < .01.

Recall Results for Specified Associate Conditions

100-300ms. There were no reliable ERP effects between any conditions during this latency.

300-500ms. Hits ($M = .49$, $SD = 2.38$) were reliably less positive than correct rejections ($M = .85$, $SD = 2.20$), at right parietal sites, $t(30) = -2.27$, $p < .05$. Hits did not differ from misses nor did misses differ from correct rejections during this latency for any electrode regions (Figures 15 & 16).

600-900ms. Misses were significantly more positive than correct rejections at left parietal sites (Misses: $M = 1.30$, $SD = 2.44$, CRs: $M = .83$, $SD = 2.23$, $t(30) = 2.55$, $p < .05$) and mid parietal sites (Misses: $M = .46$, $SD = 3.26$, CRs: $M = -.17$, $SD = 3.04$, $t(30) = 2.55$, $p = .01$)

900-1100ms. Hits were significantly more positive than correct rejections at mid parietal electrodes (Hits: $M = -.20$, $SD = 3.05$, CRs: $M = -.87$, $SD = 2.68$, $t(30) = 2.31$, $p < .05$) and right parietal electrodes (Hits: $M = -.37$, $SD = 2.53$, CRs: $M = -.82$, $SD = 2.30$, $t(30) = 2.16$, $p < .05$). Misses were also significantly more positive than correct rejections at left parietal sites (Misses: $M = .93$, $SD = 2.16$, CRs: $M = .43$, $SD = 1.87$, $t(30) = 2.69$, $p = .01$) and mid parietal sites (Misses: $M = -.12$, $SD = 2.99$, CRs: $M = -.87$, $SD = 2.68$, $t(30) = 2.92$, $p = .01$).

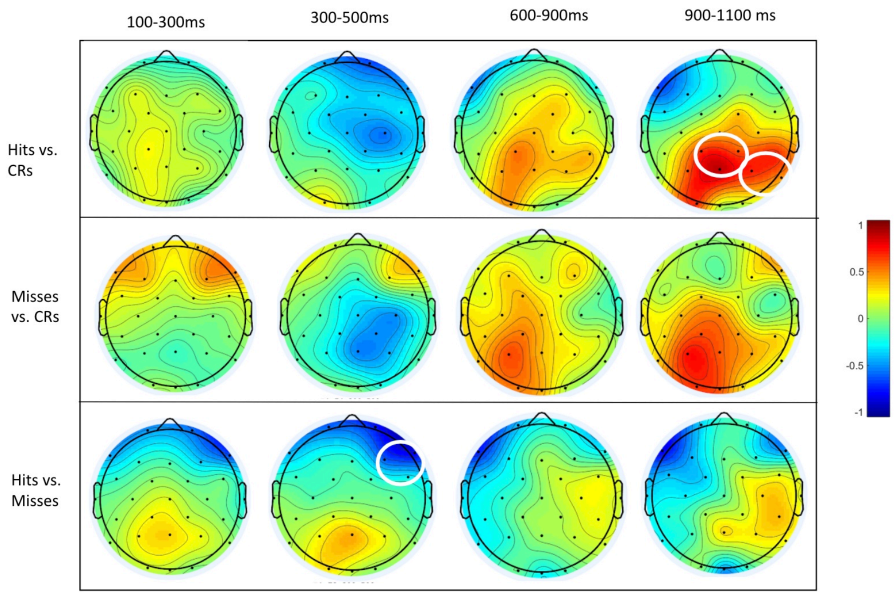


Figure 13. Topographic Maps of Recall Responses for Combined Associate Conditions. Circles indicate where electrode clusters were found to be significantly different for each of the respective contrasts noted, below a threshold of p <.05.

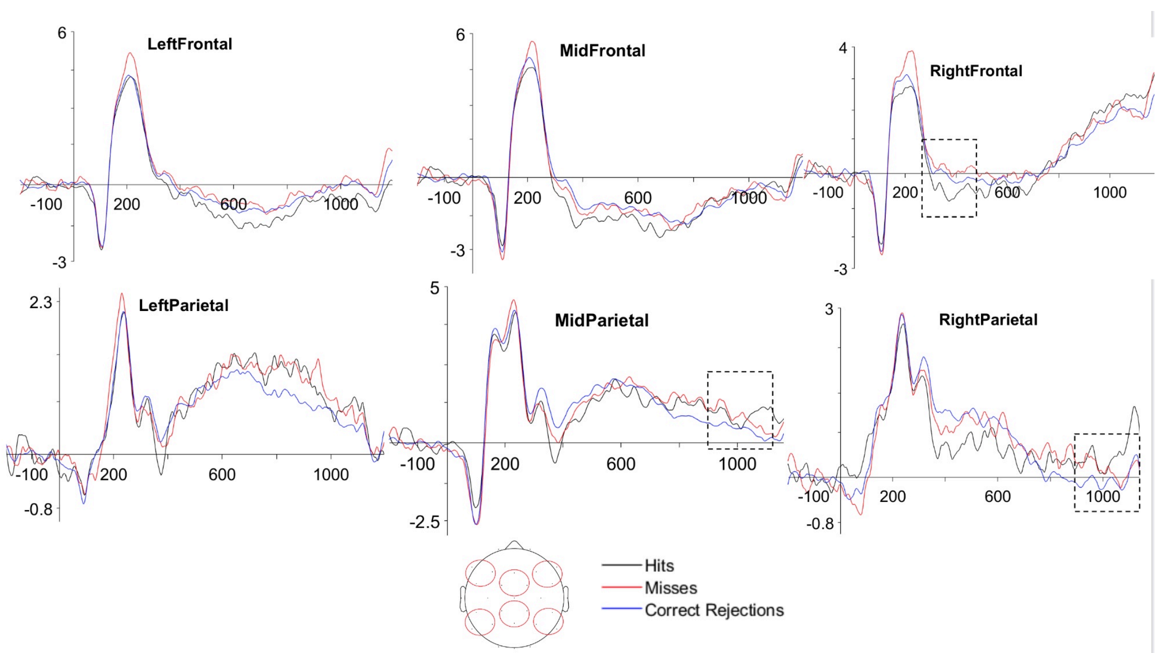


Figure 14. Event Related Potential Waveforms of Recall Responses for Combined Associate Conditions. Effects are shown for each of the six main electrode clusters analyzed, locations for which are illustrated in the representative topographic figure at the bottom. Dashed boxes indicate latencies which were found to exhibit significant effects at a level of p <.05.

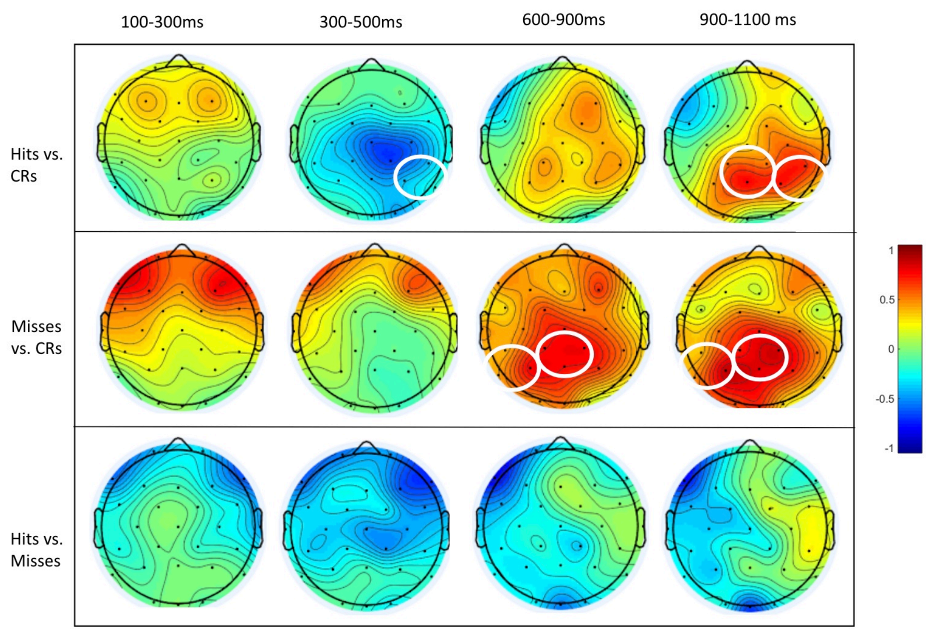


Figure 15. Topographic Maps of Recall Responses for Specified Associate Conditions. Circles indicate where electrode clusters were found to be significantly different for each of the respective contrasts noted in the figure, below a threshold of p <.05.

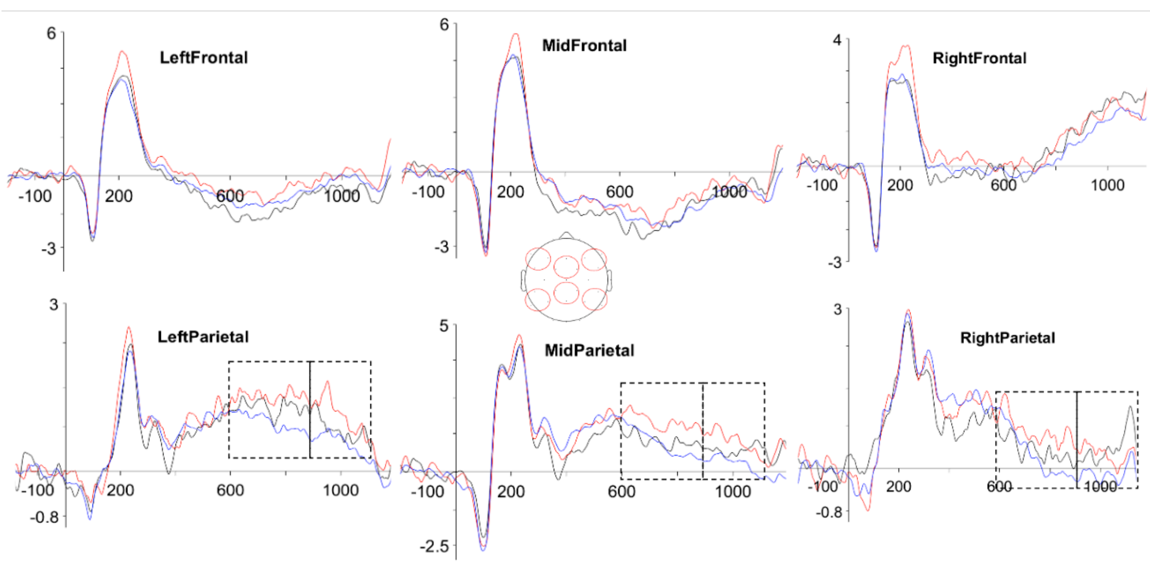


Figure 16. Event Related Potential Waveforms of Recall Responses for Specified Associate Conditions. Effects are shown for each of the six main electrode clusters analyzed, locations for which are illustrated in the representative topographic figure at the bottom. Dashed boxes indicate latencies which were found to exhibit significant effects at a level of p <.05.

Recognition Results for Collapsed Associate Conditions

We next sought to identify the ERP effects occurring during the latency when participants were answering the recognition prompt, (i.e. whether or not the word they just produced out loud was from the study phase). The rationale for this analysis was that since the conditions were defined as having been matched in recall success but varying in recognition responses, that it may be the neural activity occurring during those varied recognition trials that determines which memory process is supporting the judgments.

100-300ms. During this early latency only left frontal sites showed reliable differences between conditions. Hits ($M = -1.69$, $SD = 3.08$) were more positive than correct rejections ($M = -2.49$, $SD = 2.56$), $t(30) = 2.49$, $p < .05$. Hits were also more positive than misses ($M = -2.72$, $SD = 2.76$), $t(30) = 2.80$, $p < .01$. There were no reliable differences between misses and correct rejections during this latency for any region (Figures 17 & 18).

300-500ms. Left frontal sites showed reliable differences between hits ($M = -2.14$, $SD = 4.14$) and correct rejections ($M = -3.55$, $SD = 3.19$), $t(30) = 2.66$, $p < .05$, as well as between hits and misses ($M = -4.04$, $SD = 3.53$), $t(30) = 3.02$, $p < .01$. At this latency, hits ($M = .25$, $SD = 2.50$) were also reliably more negative than correct rejections ($M = .87$, $SD = 1.85$) at right parietal sites, $t(30) = -2.33$, $p < .05$.

600-900ms. Only left frontal sites exhibited reliable differences between conditions. Hits ($M = -.71$, $SD = 3.76$) were reliably more positive than correct rejections (M = -1.77, SD = 3.36), t (30) = 2.49, p < .05 and misses (M = -1.93, SD = 3.51), t (30) = 2.30, p < .05.

900-1100ms. Hits were significantly more positive than correct rejections at left frontal electrodes (Hits: M = -.93, SD = 3.62, CRs: M = -1.77, SD = 3.18, t (30) = 2.93, p < .01), left parietal electrodes (Hits: M = -1.01, SD = 2.61, CRs: M = -1.79, SD = 2.13, t (30) = 3.53, p < .01), and mid parietal electrode sites (Hits: M = -1.51, SD = 3.35, CRs: M = -2.43, SD = 3.12, t(30) = 3.55, p < .01). Hits were also reliably more positive than misses at mid frontal sites (Hits: M = -1.49, SD = 4.09, Misses: M = -2.28, SD = 4.27, t (30) = 2.06, p < .05) and left parietal sites (Hits: M = -1.01, SD = 2.61, Misses: M = -1.64, SD = 2.64, t (30) = 2.53, p < .05). There were no reliable differences between misses and correct rejections during this latency for any region.

Recognition Results for Specified Associate Conditions

100-300ms. At left frontal electrodes, hits (M = -1.70, SD = 2.96) were reliably more positive than misses (M = -2.81, SD = 2.67), t (30) = 3.06, p < .01. Hits did not reliably differ from misses or correct rejections (Figures 19 & 20).

300-500ms. At left frontal sites, hits (M = -2.20, SD = 3.99) were significantly more positive than correct rejections (M = -3.46, SD = 3.23), t (30) = 2.31, p < .05 and misses (M = -4.17, SD = 3.46), t (30) = 3.12, p < .01. Hits (M = .19, SD = 2.50) were less positive than correct rejections (M = .90, SD = 1.89) at right parietal sites t (30) = -2.52, p < .02. Misses were also less positive than correct rejections at left frontal sites (Misses: M = -4.17, SD = 3.46, CRs: M = -3.46, SD = 3.23, t (30) = -2.35, p < .05) and right frontal sites (Misses: M = -4.01, SD = 4.04, CRs: M = -3.09, SD = 3.45, t(30) = -2.10, p = .05).

600-900ms. At left frontal sites, hits (M = -.70, SD = 3.64) were significantly more positive than correct rejections (M = -1.64, SD = 3.42), t (30) = 2.06, p = .05 and misses (M = -2.01, SD = 3.42), t (30) = 2.46, p < .05.

900-1100ms. At left parietal sites, hits (M = -1.16, SD = 2.53), were significantly more positive than correct rejections (M = -1.69, SD = 2.28), t (30) = 2.19, p < .05.

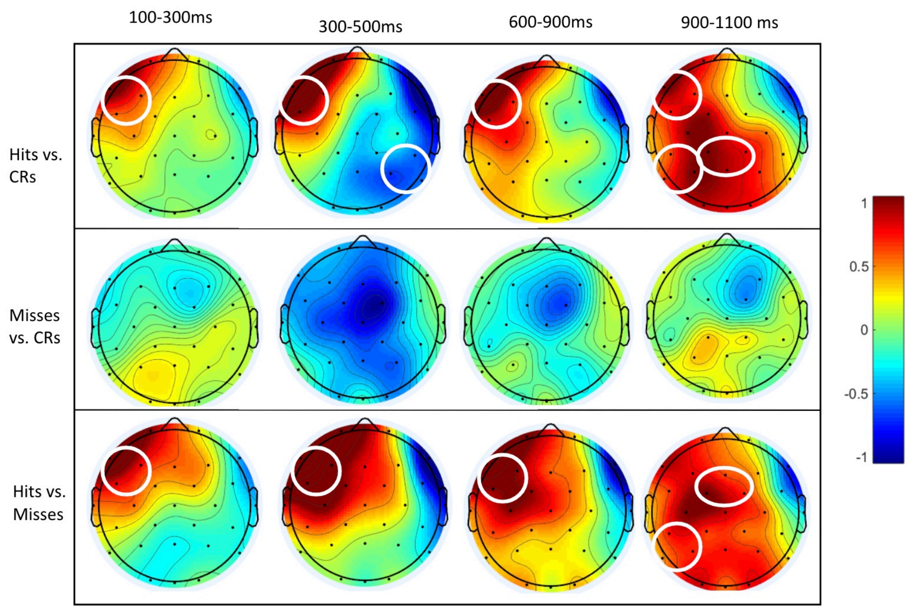


Figure 17. Topographic Maps of Recognition Responses for Combined Associate Conditions. Circles indicate where electrode clusters were found to be significantly different for each of the respective contrast, below p <.05.

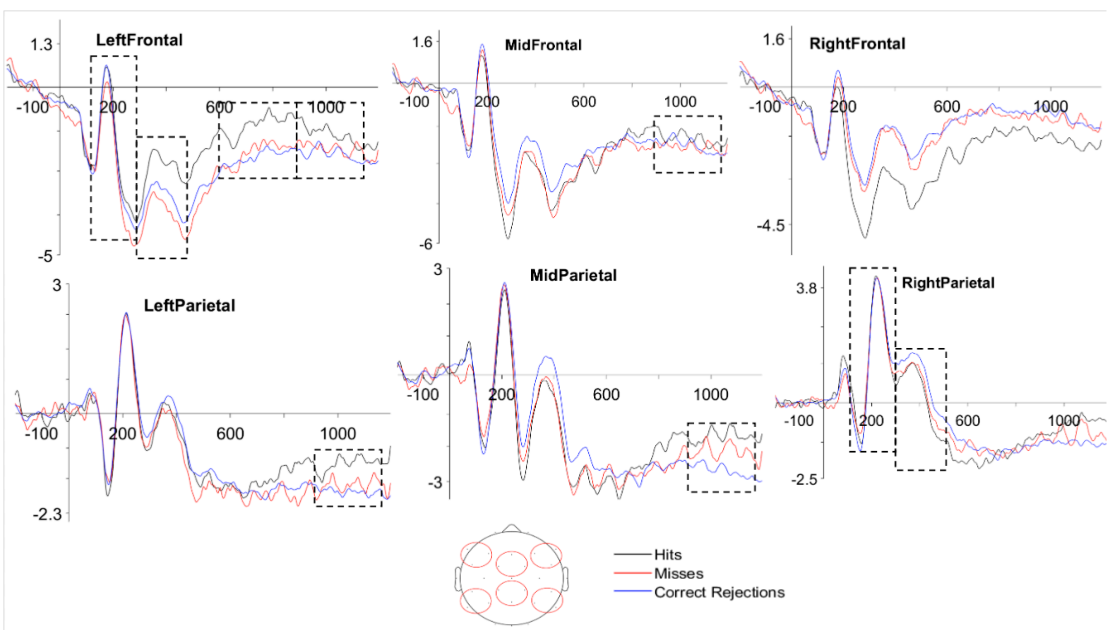


Figure 18. Event Related Potential Waveforms of Recognition Responses for Combined Associate Conditions. Effects are shown for each of the six main electrode clusters analyzed, locations for which are illustrated in the representative topographic figure at the bottom. Dashed boxes indicate latencies which were found to exhibit significant effects at a level of p <.05.

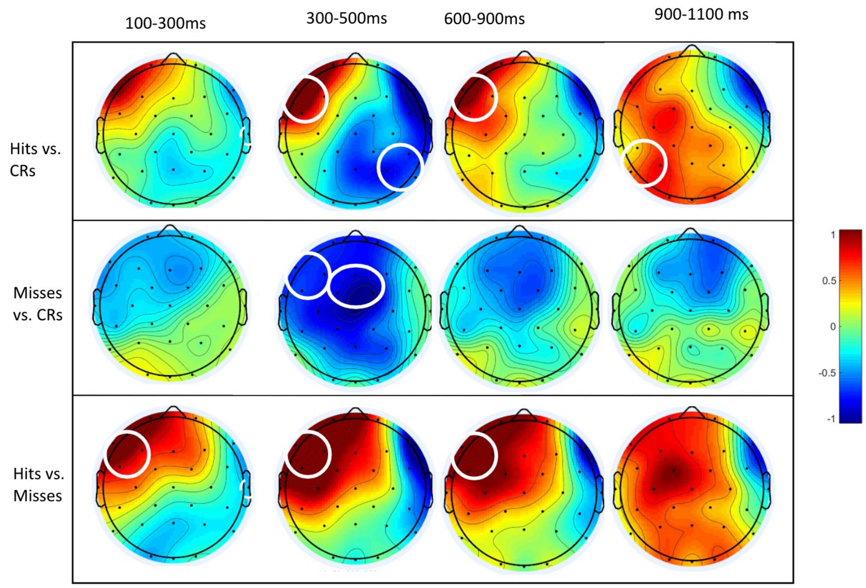


Figure 19 Topographic Maps of Recognition Responses for Specified Associate Conditions. Circles indicate where electrode clusters were found to be significantly different for each of the respective contrasts noted in the figure, below a threshold of p <.05.

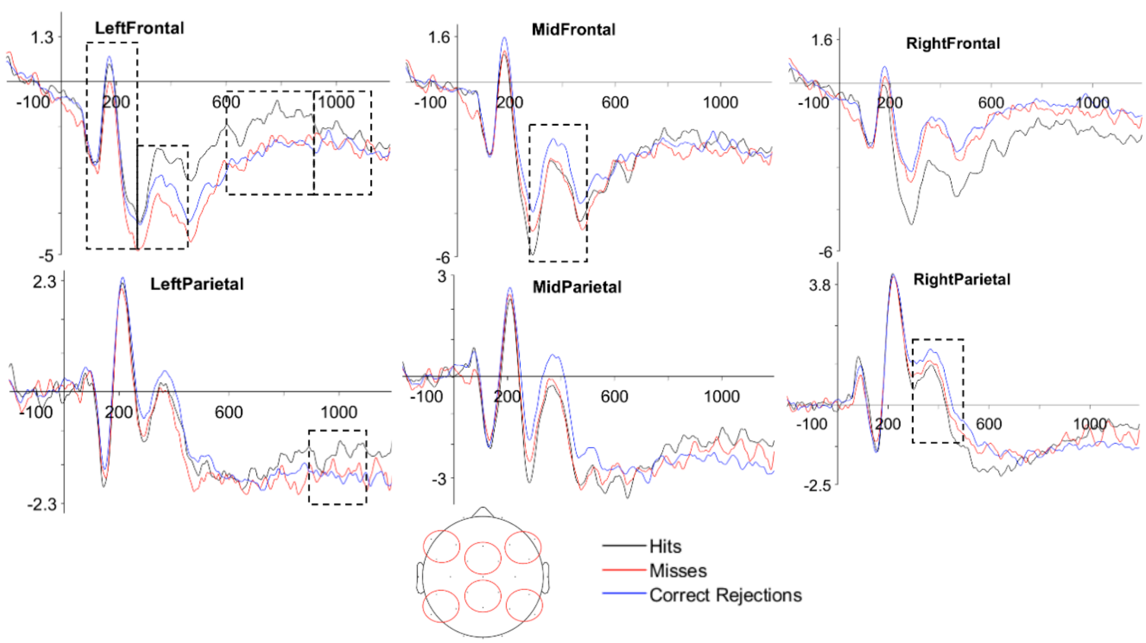


Figure 20. Event Related Potential Waveforms of Recognition Responses for Specified Associate Conditions. Effects are shown for each of the six main electrode clusters analyzed, locations for which are illustrated in the representative topographic figure at the bottom. Dashed boxes indicate latencies which were found to exhibit significant effects at a level of p <.05.

CHAPTER EIGHT

DISCUSSION

The overarching aim of the current project was to identify the neural and cognitive processes supporting or contributing to a paradoxical finding in the literature where people first recall words from the past but then miss recognizing them as having been from the past (i.e. recognition misses for cued-recall hits). Our specific goal was to assess the extent to which the findings of Ozubko et al. (unpublished) could be replicated, and then to determine the extent to which we may be able to extend those findings using more stringent and specified analysis conditions. In order to pursue these goals, we sought more statistical power in two main ways.

First, we sought to double the original sample size to our current sample of N = 40, and second, we sought to double the number of valid trials of this relatively rare memory condition so that we would have sufficient data which to analyze this effect. In order to achieve this, we doubled the number of trials to increase the total number of times in which participants missed (i.e. forgot) recognizing information recalled from the past study episodes. We also added an encoding task with a low-level of processing (Craik, Lockhart, & Jacoby, 1976) to distract the subject and further increase the number of such misses, as well as added the technological advance of a digital voice-recorder that could time-stamp instances of memory recall precisely. These all contributed to an enhanced paradigm in which we were able to increase the sample size of subjects (N) and increase the sample size of missed trials per participant (n), permitting us to make more sensitive comparisons to reveal electrophysiological effects that would not have been evident in the prior work's coarser analyses.

Misses in recall represent an unusual effect in episodic memory, in that participants are paradoxically able to recall words that they cannot then recognize as having seen before. One would typically think that if a person can successfully retrieve episodic information via recall that they would also then be able to recognize it from the past; this is an assumption shared by most models of retrieval, though there have been exceptions noted in the literature (Allan & Rugg, 1998; Angel, Fay, et al., 2010; Angel et al., 2009; Angel, Isingrini, et al., 2010 ; Rugg, Fletcher, et al., 1998). This phenomenon is particularly unusual since recall is considered a more taxing retrieval process than recognition, so one would infer that a word that can be recalled should also be recognized. Although recall relies more heavily on explicit memory than recognition, there are other cognitive processes that may contribute to recall; for example recall misses could be driven by implicit priming (Ozubko et al, unpublished).

In the current study, we were able to replicate the behavioral findings and several physiological effects observed by Ozubko and colleagues. Our behavioral results indicate faster reaction times for hits than misses and correct rejections at recognition, suggesting an ease of processing or "fluency" effect. Although Ozubko and colleagues did not measure reaction times for the recall response, we thought it would provide valuable insight about the processes recruited to produce such responses. At recall prompts, participants were faster to respond with an old word that was a cue-target pair, than they were to respond with any old word that was from the study phase that was not a pair, and faster than they were to produce a new word (Figure 7). Interestingly, when looking at the combination of recall and recognition responses together, the “no memory condition” (N_New_CR) had the slowest response times, compared to all other conditions for both the recall and recognition portion of the combined response. Also, successfully recognized recalled words (S_OldPair_Hit) had the fastest response times for both the recall and recognition portion of the combined response. It is also important to note that our main comparison of interest, recognition failure of recalled words (S_OldPair_Miss) had slower reaction times than successfully recognized recalled words (S_OldPair_Hit) for the recognition portion of the combined response (Figures 11 & 12). The differences between the reaction times in these conditions may represent a sequential search process in which participants search available memory for an old word (S_OldPair) and then if they fail to remember a word, must think of a new word (N_New). When asked if the word they produced was old or new, participants would also have to sequentially search available memory to decide if the word they produced was old (Hit) or new (Miss or Correct Rejection, depending on if the word was actually old or new).

The physiological results of Combined Associate Conditions (CAC) indicate recollection at the recall prompt. A late parietal component (LPC) was identified for hits compared to correct rejections at mid-parietal and right parietal electrode sites at 900-1100ms (Figures 13 & 14), which is characteristic of recollection memory (Addante, Ranganath, & Yonelinas, 2012; Friedman & Johnson, 2000; Rugg & Curran, 2007). In replicating the same conditions and analyses as Ozubko and colleagues, no correlates of familiarity or implicit memory were found.

There are several reasons why we believe this study did not replicate all the findings of Ozubko and colleagues. Based on the improvements made to the experimental design, there may have been disadvantages of the original design, which may have contributed to unreliable effects. It is also possible that the hypothesized effects were not observed due to the epoch chosen for analysis. The epoch analysis initially used was from -200 to 1200 ms post stimulus onset when participants were presented a cue word to process for ensuing cued recall of a paired target for that cue. We analyzed this epoch primarily to remain consistent with the approach used by Ozubko et al., since we sought to replicate those findings. This first analysis focused on EEG epochs of when subjects were processing the cue word to make a recall response, but not on EEG from the times from when performing a recognition judgment about their recall response. Upon reflection, we reasoned that the conditions being compared (recall hits that became recognition hits: Hit_Hits, and recall hits that became recognition misses: Hit_Misses) were each actually defined as the same conditions during recall (recall hits), and that if we were seeking to understand why these behavioral conditions differed that we should also assess the physiology during the actual times in which the cognitive processes were happening that differentiated these conditions: recognition.

We hence conducted a further investigation of the recognition epochs, which revealed physiological correlates of familiarity- and recollection-based processing. An early FN400 effect, which is considered a putative neural correlate of familiarity (Friedman & Johnson, 2000; Rugg & Curran, 2007) emerged around 100-300ms and persisted throughout the epoch at left frontal sites when comparing hits to correct rejections and to misses (Figures 17 & 18). Correlates of recollection (LPC) were also identified for hits compared to correct rejections and for hits compared to misses for 900-1100ms post stimulus onset. As previously mentioned, due to the more demanding nature of recall, we expected to find physiological correlates of familiarity and recollection delayed roughly 200ms. However, for the recognition analysis, we did not expect the physiological effects of recollection and familiarity to be delayed because during this time period participants no longer had to produce a word, but simply had to rate the word that they already produced as being old or new.

Interestingly, no correlates of implicit memory were found for either the recall or recognition analysis when we analyzed the original conditions investigated by Ozubko and colleagues (Combined Associate Conditions). As described earlier in their original approach, Ozubko and colleagues collapsed words produced from semantic associate cues and non-associate cues together into the same conditions, counting items as successfully recalled regardless of which cue initiated their retrieval, a frequently used practice in the recall literature (e.g., Ozubko, 2016; Blaxton, 1989; Humphreys & Galbraith, 1975; Thomson & Tulving, 1970; Tulving & Osler, 968). Not specifying conditions based on whether responses were generated from semantic associate cues or non-associate cues may conflate processes if in fact distinct processes are used to arrive at these recalled items. We reasoned that it may be possible to gain a more sensitive measure of our conditions of interest if we used an approach that distinguished more specific conditions, based on whether a word was produced in response to a semantic associate or non-associate cue.

Generically, recognition hits (Hit_Hits) displayed different patterns of physiological activity than misses at recognition (Hit_Misses), suggesting they are derived from different cognitive processes. Hits were specifically characterized by early positive frontal activity, consistent with FN400 effects typically reported in the literature for familiarity-based processing[7] (Friedman & Johnson, 2000; Rugg & Curran, 2007). Hits also showed late positive parietal activity that suggests recollection. However, misses do not exhibit these same

[7] We do not believe that the early frontal activity was due to blinks, as several measures were taken to remove them from the data (see methods). Also, the frontal activity present for hits represents blinks because it is not evident for misses, and in both conditions participants see the same "Old/New" screen, and would hypothetically move their eyes the same amount in each condition. One account for misses could be that participants are simply not paying attention, and thus do not exhibit the same eye movements, but this is unlikely because there is evidence of some cognitive process occurring. However, future research can take measures to counterbalance the "Old/New" screen so that eye movements cancel out, but caution should be exercised in that this may cause confusion and accidental incorrect responses.

effects of recollection or familiarity, but do exhibit a mid-frontal negative effect[8], which has been found by other studies to represent repetition fluency (Leynes & Zish, 2012). It is possible that repetition fluency was present for hits, but just overpowered by the stronger processes of familiarity and recollection.

An important contribution of this project was the extra analysis that separated associate conditions. Because of this analysis, we were able to examine effects that would have otherwise remained undetected by traditional, coarser methods of analysis. When contrasting the physiological activity for the two epochs of interest (recall and recognition), overall, recall hits that went on to become recognition hits (S_OldPair_Hit) show a different pattern of activity than recall hits that went on to become recognitions misses (S_OldPair_Miss), as described below.

At recall, hits (OldPairs) produced a LPC effect around 900-1100ms, which suggests its association with the putative neural correlates of recollection (Rugg & Curran, 2008). Then at recognition, this same condition of hits was supported by early correlates of familiarity at left frontal sites that persisted through the epic and followed by recollection, as the LPC emerged again at 900-1100ms in parietal regions (Figures 15 & 16). Thus, Hit_Hits (S_OldPair_Hits) seem to be supported by a combination of recollection and familiarity: first by recollection at recall epochs, and then by familiarity and recollection at recognition epochs.

[8] This effect is not significant in the CAC conditions, but is significant in the SAC conditions later described.

On the other hand, the activity found for Hit_Misses (S_OldPair_Miss) was different from that described for Hit_Hits. At recall, a positive parietal effect appeared at 600-900ms that might be thought to indicate recollection-related processing. However, a more logical explanation of this effect suggests that it may represent semantic priming, because it occurs earlier than recollection effects evident in the Hit_Hit condition and it does not support subsequent memory in the recognition latency or behavior that the Hit_Hit LPC did (Addante, 2015; Addante, Ranganath, Olichney, & Yonelinas, 2012; Addante, Ranganath, & Yonelinas, 2012; Bridger et al., 2012; Li, Mao, Wang, & Guo, 2017; Rugg, et al., 1998; Yu & Rugg, 2010; Bader & Mecklinger, 2017).

In the recognition ERP data, Hit_Misses did not exhibit ERP effects of explicit memory processes such as familiarity and recollection, but were instead characterized by an early frontal negative-going effect that emerged around approximately 300-500ms, which was not present in the Hit_Hit condition (Figure 19 & 20). This effect is highly consistent with other left-frontal negative-going ERP effects reported for repetition fluency (Leynes & Zish, 2012; Leynes & Addante, 2016) and is similarly consistent with left-frontal negative-going ERP effects reported for context familiarity (Addante, 2012; Montaldi & Mayes 2010). This fluency or context familiarity pattern of activity found for S_OldPair_Miss was only seen in the Specified Associate Conditions, and not in the Combined Associate Conditions (Figures 21 & 22). Based on the data, we thus infer that combining conditions for non-associate and semantic associate words may dilute the priming effects by combining slightly different conditions together, which evidently represent reliably different neurocognitive processing.

For Hit_Misses, it appears that participants first experience semantic priming at recall when they produce an old word from the study list, and then the word they produce is implicitly detected via repetition fluency or context familiarity (with the semantic nature being the familiar context). This item is evidently lacking the conscious/explicit processing of item familiarity or recollection that would have been evident in an FN400 or LPC effect, respectively, like those observed for Hit_Hits (in this manner, the Hit_Hits condition serves as a form of a control condition to exemplify what recollection/LPC processing would look like in the current paradigm, and which we can compare the Hit_Miss effects to for context).

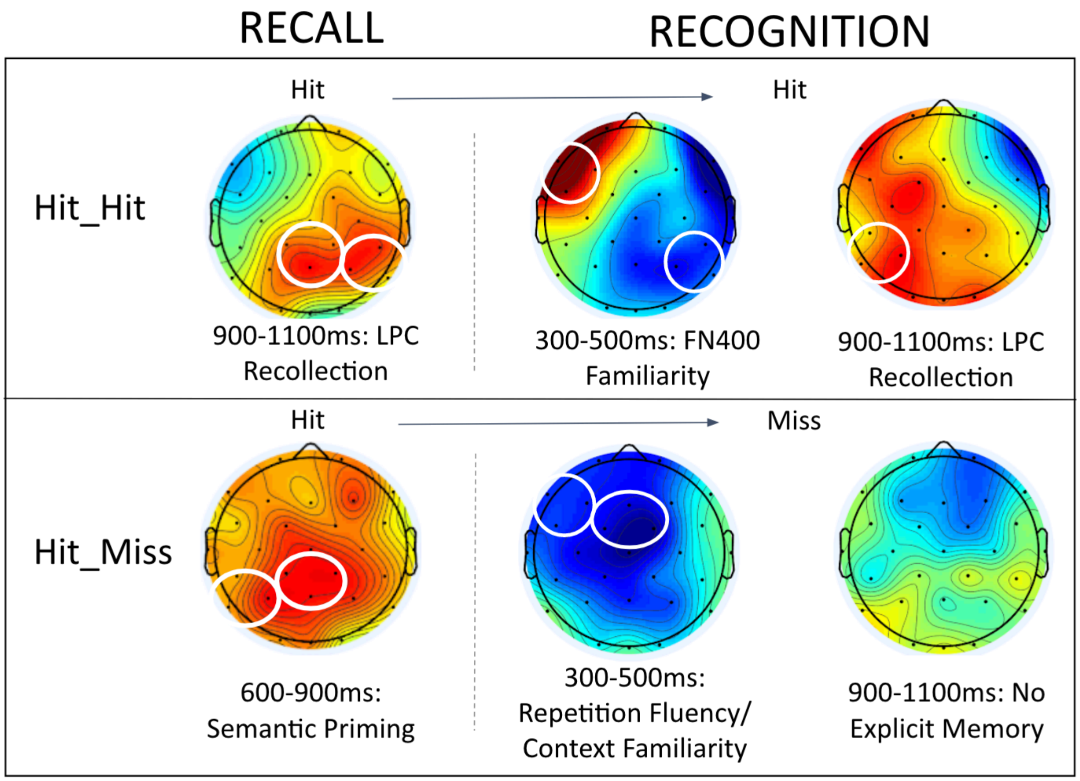


Figure 21. Summary Model of the Event Related Potential Data on Recall and Recognition Patterns for Semantic Associate Conditions. Data draws from Figures 15 and 19, and illustrates the temporal sequence of activity as participants first process recall judgments for cued semantic associates, followed by old/new recognition judgments about the items the just produced in the preceding recall response (see Figure 3 for paradigm information). To make difference waves, correct rejections are subtracted from each of the conditions of interest in order to remove any “non memory” activity.

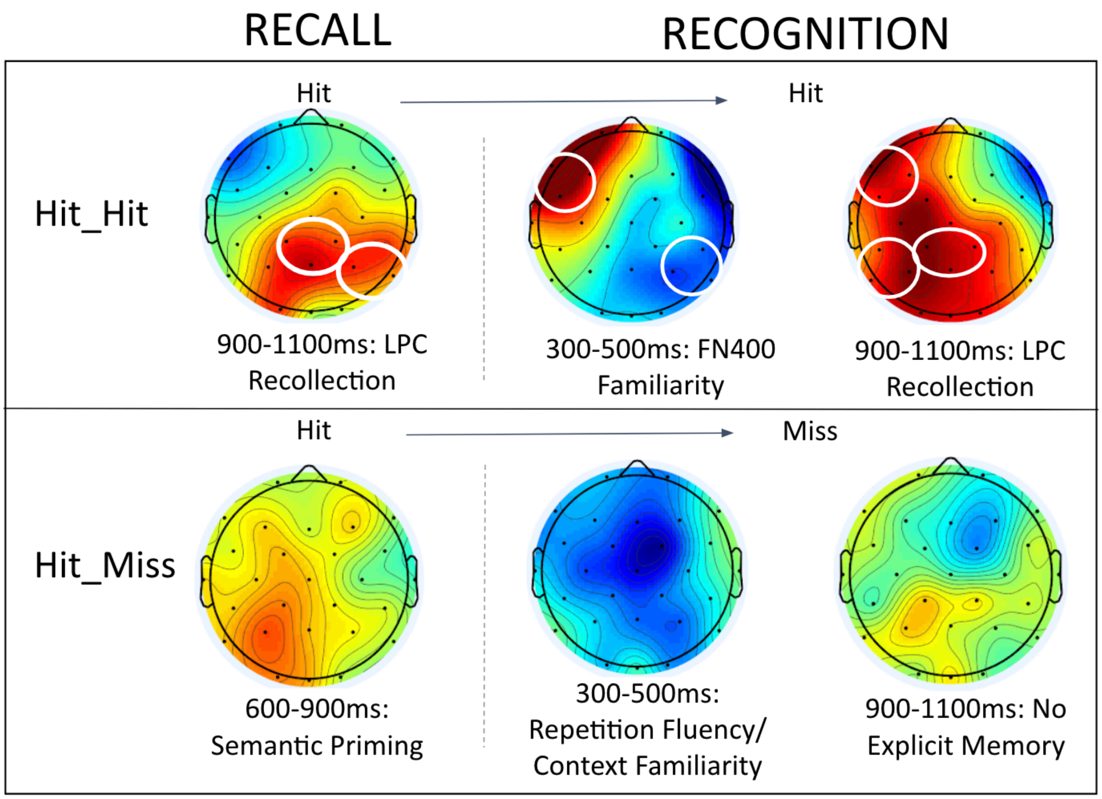
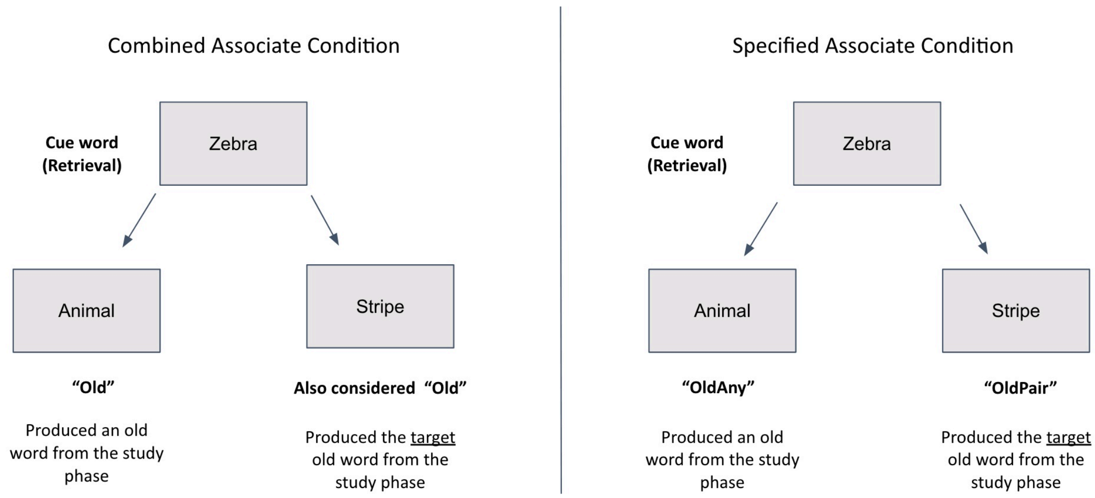


Figure 22. Summary Model of the Event Related Potential Data on Recall and Recognition Patterns for Combined Associate Conditions. Data draws from Figures 13 and 17, and illustrates the temporal sequence of activity as participants first process recall judgments for both cued semantic associates and non associates, followed by old/new recognition judgments about the items the just produced in the preceding recall response (see Figure 3 for paradigm information). To make difference waves, correct rejections are subtracted from each of the conditions of interest in order to remove any "non memory" activity.

In conclusion, though the study set out to investigate the extent of replicability of prior findings, and at first was unable to replicate those prior findings using that prior study's general conditions, the current investigation ultimately did find the prior effects to be replicated when we applied a more specific procedure to exclude confounding conditions. These more specific analyses were thus essential in replicating these effects and extending them in novel ways. Separating recall and recognition responses based on whether they originated from semantic or non-associate cues may thus be an important advance in future studies, since separating these conditions revealed effects that were not significant when the conditions were collapsed. Additionally, the phenomenon of recall misses can be explained by a combination of implicit cognitive processes including semantic priming, repetition fluency and potentially even context familiarity. Failed recognition judgments of words that are successfully recalled do not rely on early familiarity or later recollection, but are evidently solely reliant upon the activity associated with early semantic priming.

Overall, the current study made several contributions to the literature. First, it successfully demonstrated the ability to integrate voice-key technology into episodic memory paradigms to precisely capture the precision of recall responses while concurrently recording electrophysiology from EEG. Second, the current investigation created several innovations for studying combined responses of recall and recognition in cued-recall paradigms. We found that existing approaches (i.e. Ozubko et al,) for measuring memory conditions can be broken down into distinct cognitive conditions, and that when this is done they revealed different physiological patterns than what would have been detected otherwise. Third, the study also took the unusual step of analyzing sequential episodic memory epochs of both recall and recognition, identifying the differential patterns of neural activity occurring in each to support complex forms of memory retrieval. Finally, these innovations converged to reveal novel insight into how and why recall hits can be followed by recognition misses of the same items. It appears that this is due to cued-semantic priming during recall followed by repetition fluency during recognition in the absence of explicit familiarity and recollection. This suggests that future work can obtain further insight into these memory processes using similar approaches, and thereby reveal the unique neurocognitive processes underlying different types of recognition and recall.



Supplemental Figure 1. Paradigm Schematic for Differentiating Between Collapsed Associate Conditions (Left) and Specified Associate Conditions (Right). The Combined Associate Condition (CAC) does not differentiate between words produced that are the target word, or just any old word from the study phase. It also does not differentiate between semantic associate and non-associate cues. The Specified Associate Condition (SAC) differentiates whether the old word produced was the target pair to the cue word, or just any old word from the study phase. This condition also differentiates whether the cue was an associate or non-associate cue.

APPENDIX A

INSTITUTIONAL REVIEW BOARD

February 19, 2019

CSUSB INSTITUTIONAL REVIEW BOARD
Protocol Change/Modification
IRB-FY2019-113
Status: Approved

Richard Addante
CSBS - Psychology
California State University, San Bernardino
5500 University Parkway
San Bernardino, California 92407

Dear Richard Addante :

The protocol change/modification to your application to use human subjects, titled "Cognitive Neuroscience of Memory" has been reviewed and approved by the Chair of the Institutional Review Board (IRB). A change in your informed consent requires resubmission of your protocol as amended. Please ensure your CITI Human Subjects Training is kept up-to-date and current throughout the study.

You are required to notify the IRB of the following by submitting the appropriate form (modification, unanticipated/adverse event, renewal, study closure) through the online Cayuse IRB Submission System.

1. If you need to make any changes/modifications to your protocol submit a modification form as the IRB must review all changes before implementing in your study to ensure the degree of risk has not changed.
2. If any unanticipated adverse events are experienced by subjects during your research study or project.
3. If your study has not been completed submit a renewal to the IRB.
4. If you are no longer conducting the study or project submit a study closure.

You are required to keep copies of the informed consent forms and data for at least three years.

If you have any questions regarding the IRB decision, please contact Michael Gillespie, Research Compliance Officer. Mr. Gillespie can be reached by phone at (909) 537-7588, by fax at (909) 537-7028, or by email at mgillesp@csusb.edu. Please include your application identification number (above) in all correspondence.

Best of luck with your research.

Sincerely,

Donna Garcia

Donna Garcia, Ph.D, IRB Chair
CSUSB Institutional Review Board

DG/MG

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